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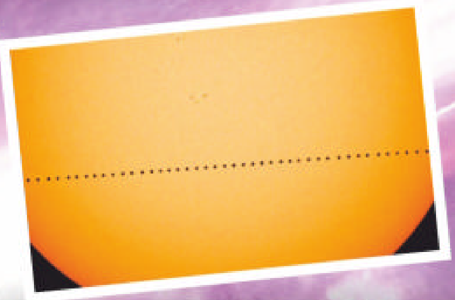

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Quasars shoot powerful jets of energy that can be detected from Earth

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Welcome

What is phantom energy? You'd be correct in thinking that its cousin is the mysterious dark energy. And just like it, cosmologists are scratching their heads on its true identity. We have a rough idea that dark energy exists in the universe due to cosmic expansion, but currently we're still trying to prove the existence of its ghostly relative. You'll remember that the Hubble Space Telescope revealed that the cosmos is expanding quickly - or at least much faster than we initially measured - now we could have an explanation for it, and phantom energy could be the culprit.

What does this mean for the fate of the cosmos? Essentially, when anything expands too quickly, it tends to tear, and the universe is of no exception: we'd be left with something known as the Big Rip, an end point in the fabric of space and time. In this scenario, everything in the universe - the stars that are visible in the night sky, the galaxies that pepper the cosmos and the extrasolar worlds that litter every corner - will be torn apart.

As ever though, the jury's out on how the universe will end - that is, if it ever will. Turn to page 16 for the full report on where we're at in finally uncovering more about one of the most mysterious forces that could permeate space.

We've brought you a peek into 2020 early this year, so turn to page 34 for some unmissable events. Plus, enjoy your free calendar!

Gemma Lavender
Editor-in-Chief

Our contributors include...

Giles Sparrow
Space science writer
Jupiter has a deadly secret in the form of Earth-destroying asteroids. Giles chats to the researchers on what this could mean for our future.

Matt Balme
Planetary Scientist
What can we learn from the winds of Mars? Matt uncovers how they're vital for ExoMars' role in finding out more about the Red Planet's past.

Jonathan Fortney
Astronomer
Answering your questions about the universe this month, Jonathan is joined by astronomers from all over the world to reveal secrets of the cosmos.

James Romero
Science writer
James uncovers how caves in the Solar System could be essential in our future plans for manned space exploration as well as protecting colonies.

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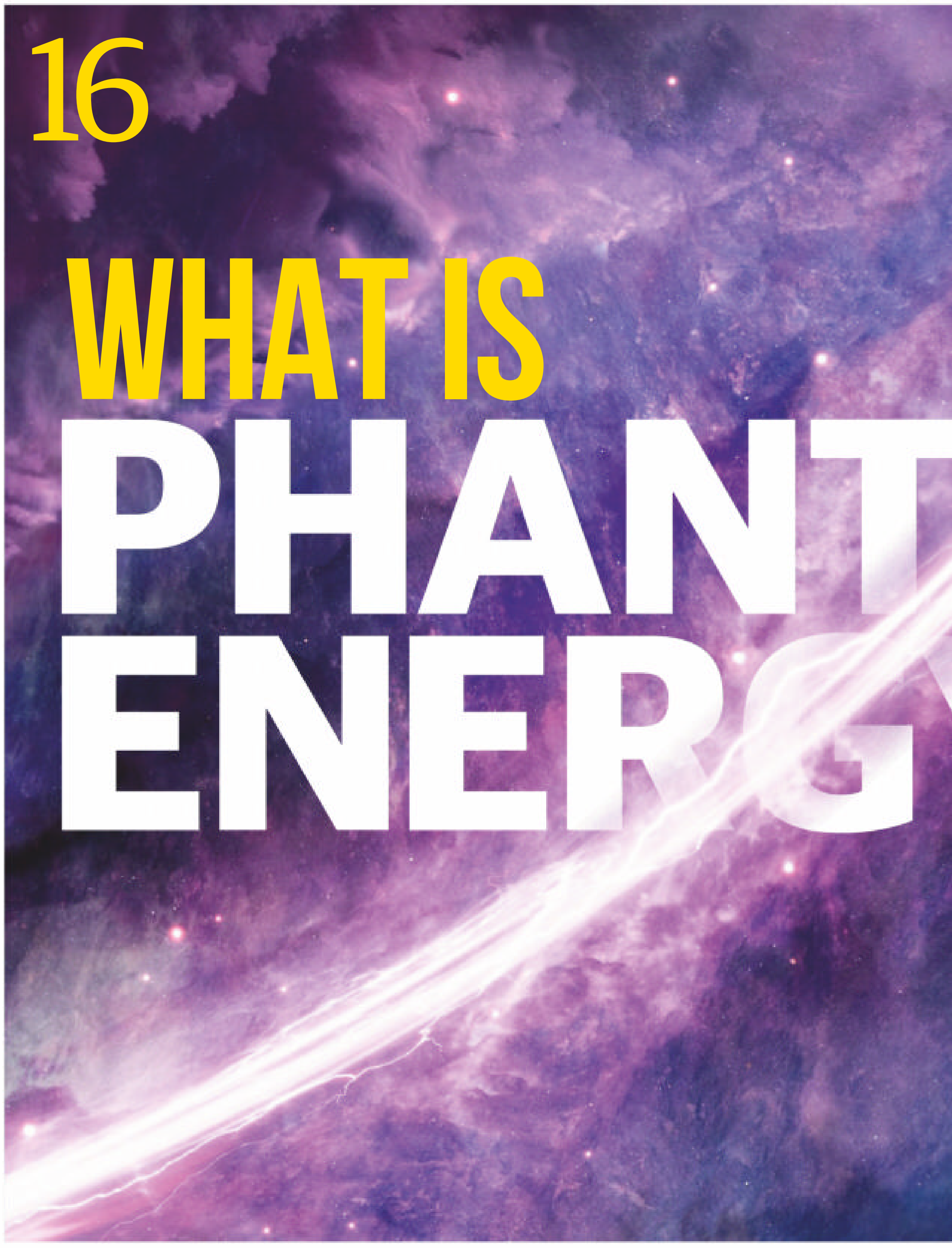

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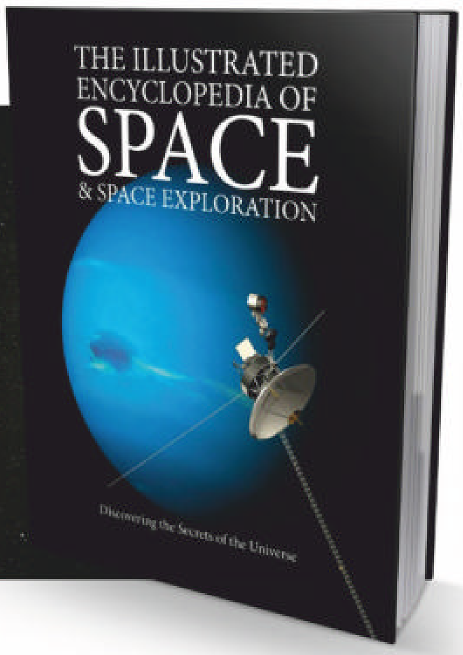
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> "More recently we are seeing things like sand dunes, even quite big ones, moving on Mars"

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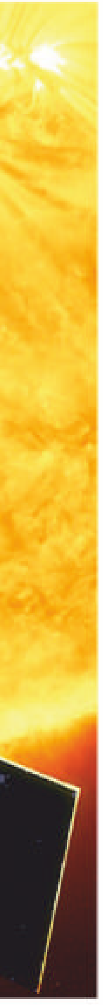

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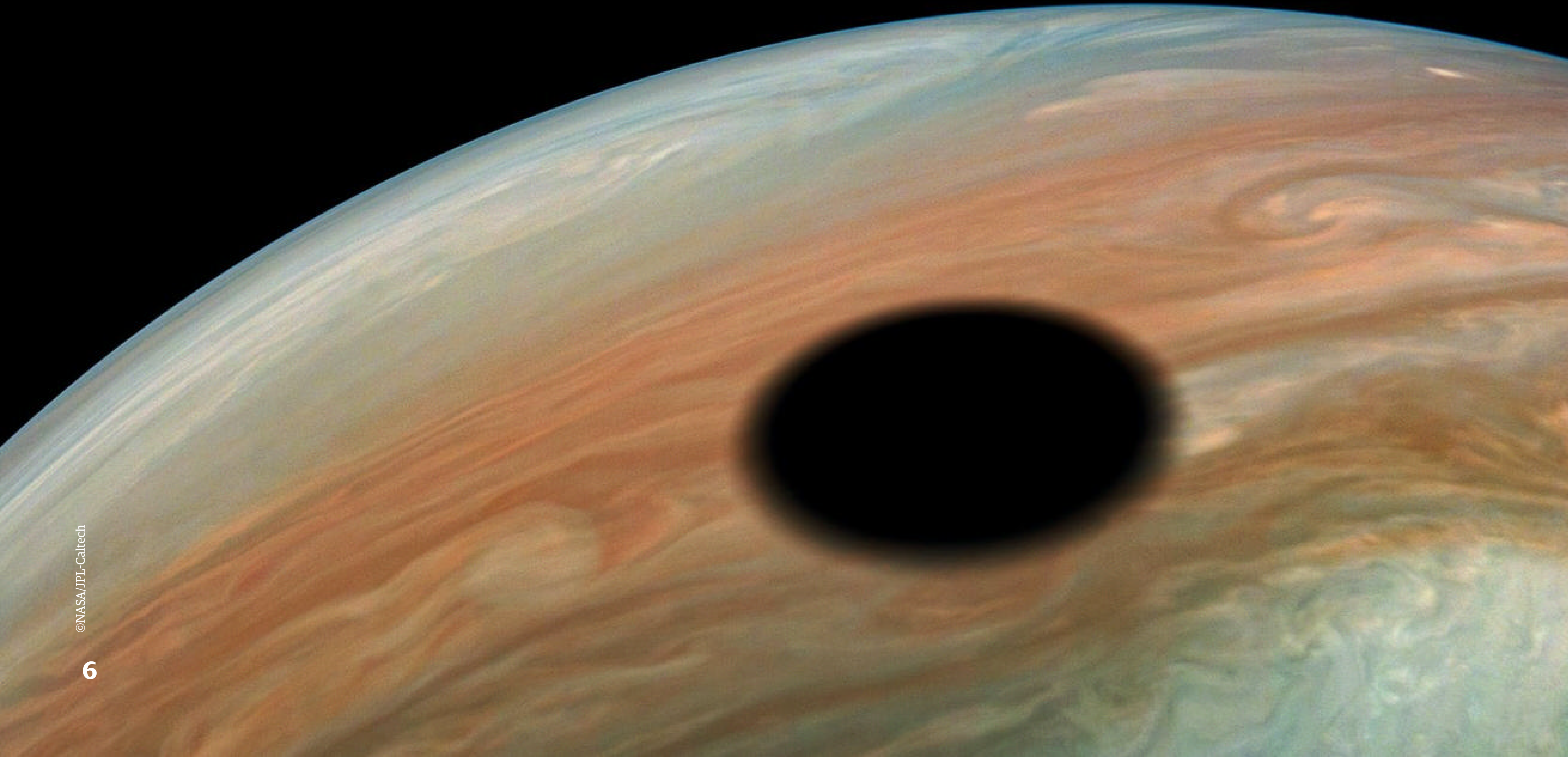
Io casts its shadow

This is not a humongous hole that has suddenly appeared on Jupiter, but instead the shadow of its closest Galilean moon, Io. Captured by NASA's Juno spacecraft, which is still currently operating at the Jovian giant, this picture shows an eclipse over the world's swirling, multi-coloured clouds. The shadow stretches about 3,600 kilometres (2,200 miles) across the cloud tops, which is just 200 kilometres (124 miles) short of the diameter of the Moon.



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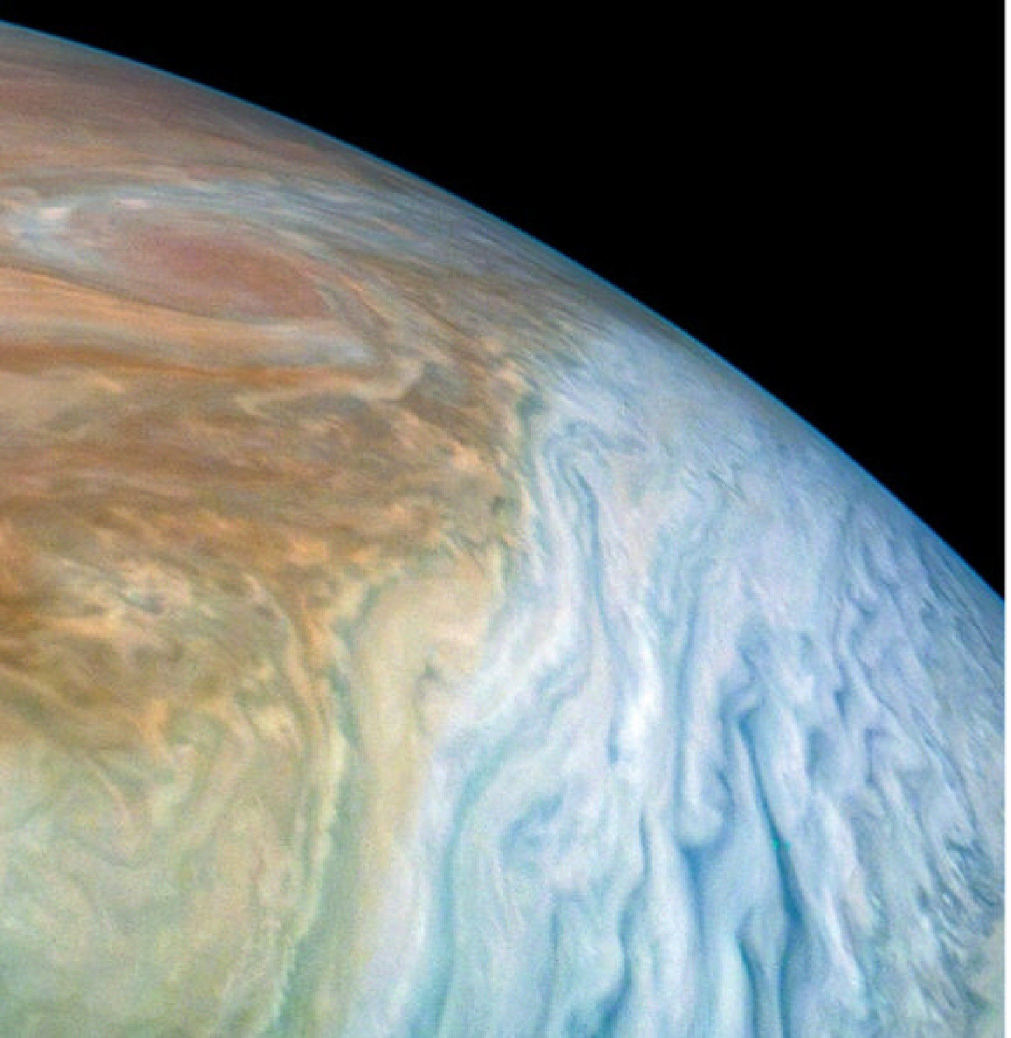

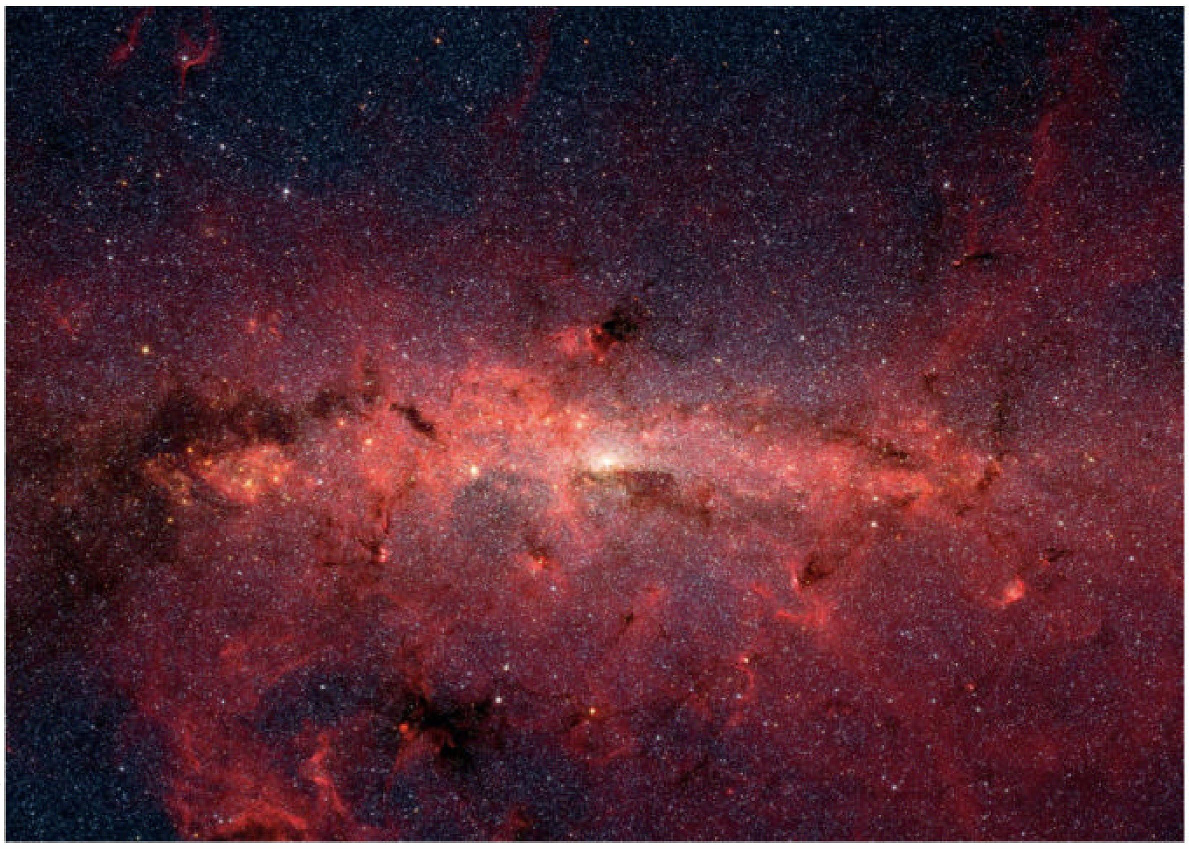

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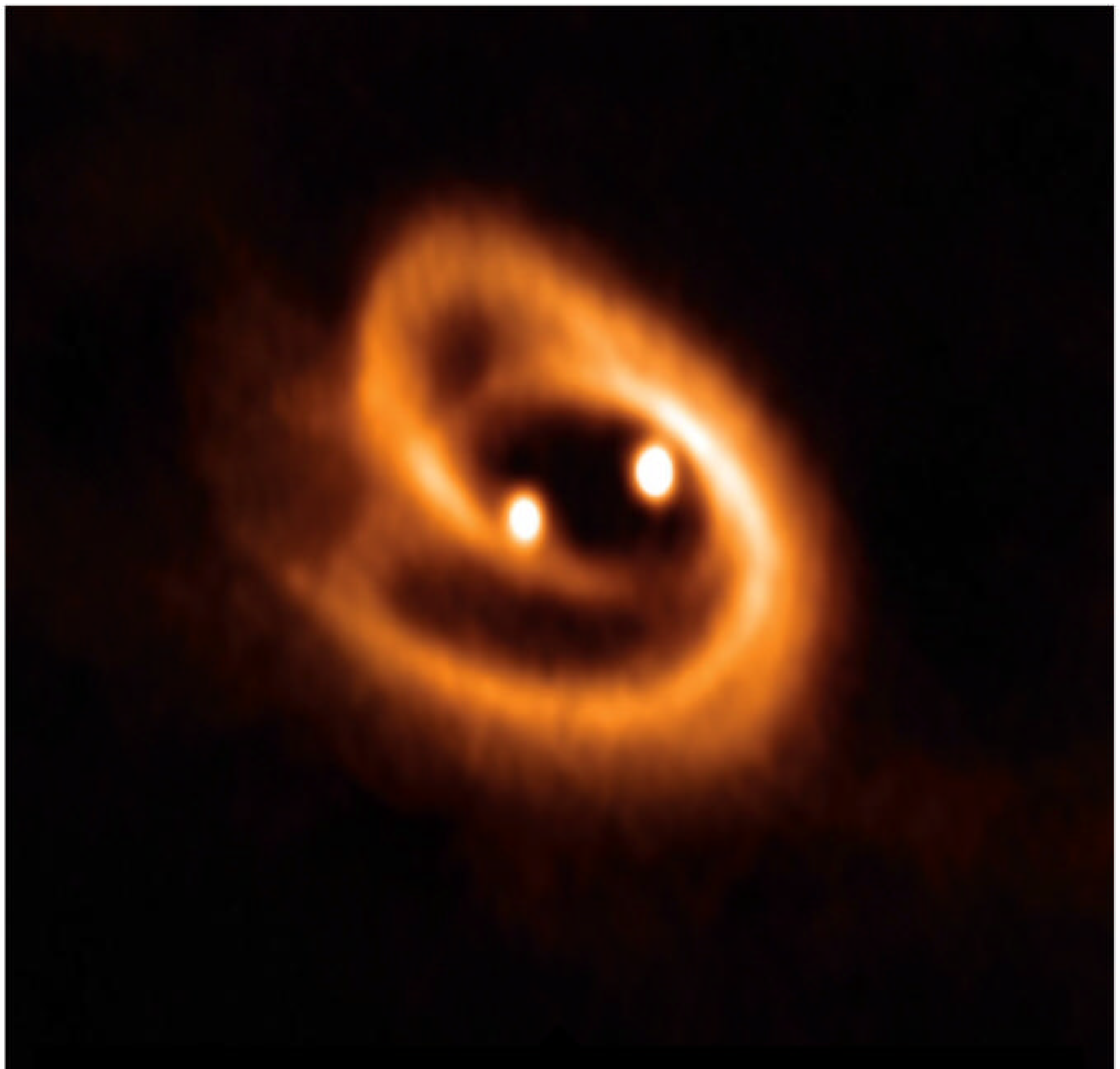
The Milky Way's red reveal

The Milky Way is a remarkable sight, but it can be even more remarkable through the eyes of NASA's Spitzer Space Telescope. Spitzer is an infrared telescope, so it sees light in a wavelength that is invisible to human eyes. Peering at our galaxy, it has uncovered the dust and gas illuminated by the billions of stars scattered along the plane. It's not just about creating beautiful pieces of celestial art, however. The Spitzer Space Telescope is key in understanding what lies behind the dust, as infrared can penetrate through the interference and get to our Milky Way's secrets.



A sight you 'knead' to see

The 'Cosmic Pretzel' is the name coined for this image of two baby stars twisted and tangled in a pretzel-shaped string of filaments of gas and dust. The two stellar siblings were spotted in a small cluster of stars in the Barnard 59 dark nebula by the European Southern Observatory's Atacama Large Millimeter/submillimeter Array (ALMA) in Chile. This network of filaments is being perceived as a circumstellar disc, essentially the material stars digest as they grow. Each disc is similar in size to the asteroid belt in our Solar System, and the distance between the two stars is 28-times the distance between the Sun and Earth.

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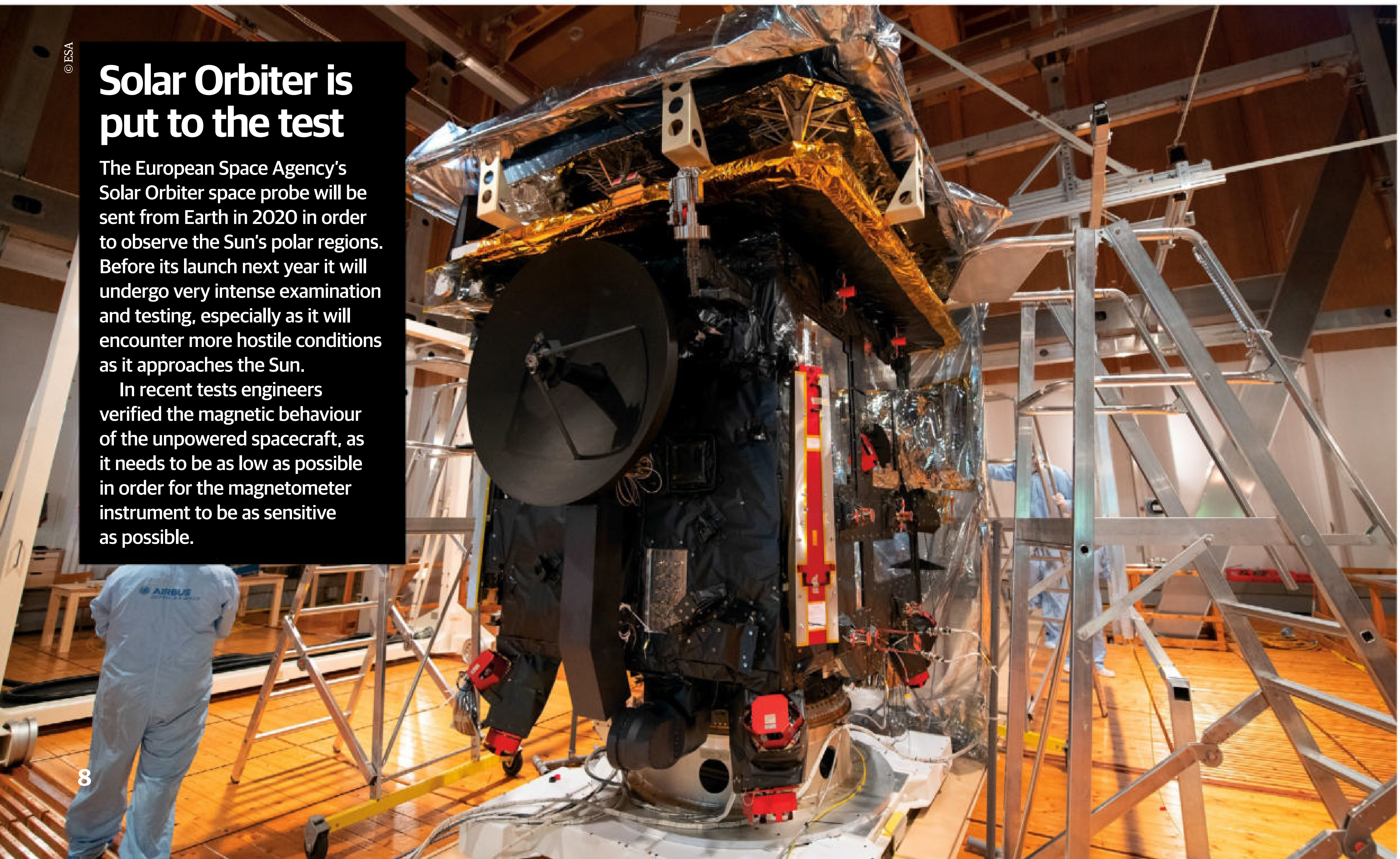
Brad Pitt boards the Mars 2020 rover

NASA has created a fun way to make its missions more accessible by allowing members of the public to send their names on the Mars 2020 rover. This is a campaign that proved successful with the InSight mission, with almost two-and-a-half million people submitting and recieving a 'boarding pass'.

Here, famous actor Brad Pitt picked his up during a visit to NASA's Jet Propulsion Laboratory (JPL) in California on 6 September 2019. To the left of Pitt is the Mars 2020 project systems engineer Jennifer Trosper.



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Solar Orbiter is put to the test

The European Space Agency's Solar Orbiter space probe will be sent from Earth in 2020 in order to observe the Sun's polar regions. Before its launch next year it will undergo very intense examination and testing, especially as it will encounter more hostile conditions as it approaches the Sun.

In recent tests engineers verified the magnetic behaviour of the unpowered spacecraft, as it needs to be as low as possible in order for the magnetometer instrument to be as sensitive as possible.

Man versus the universe

The majesty of the Milky Way is a powerful and profound sight. One location that is perfect for viewing the streak of light, splattered with dark and dusty streaks is the Atacama Desert in Chile. This desert is ideal for making astronomy observations because it is dry, remote and rarely sees a cloudy night – not only is that important for observations using the world's busiest telescopes, but it's quite easy on the naked eye as well.

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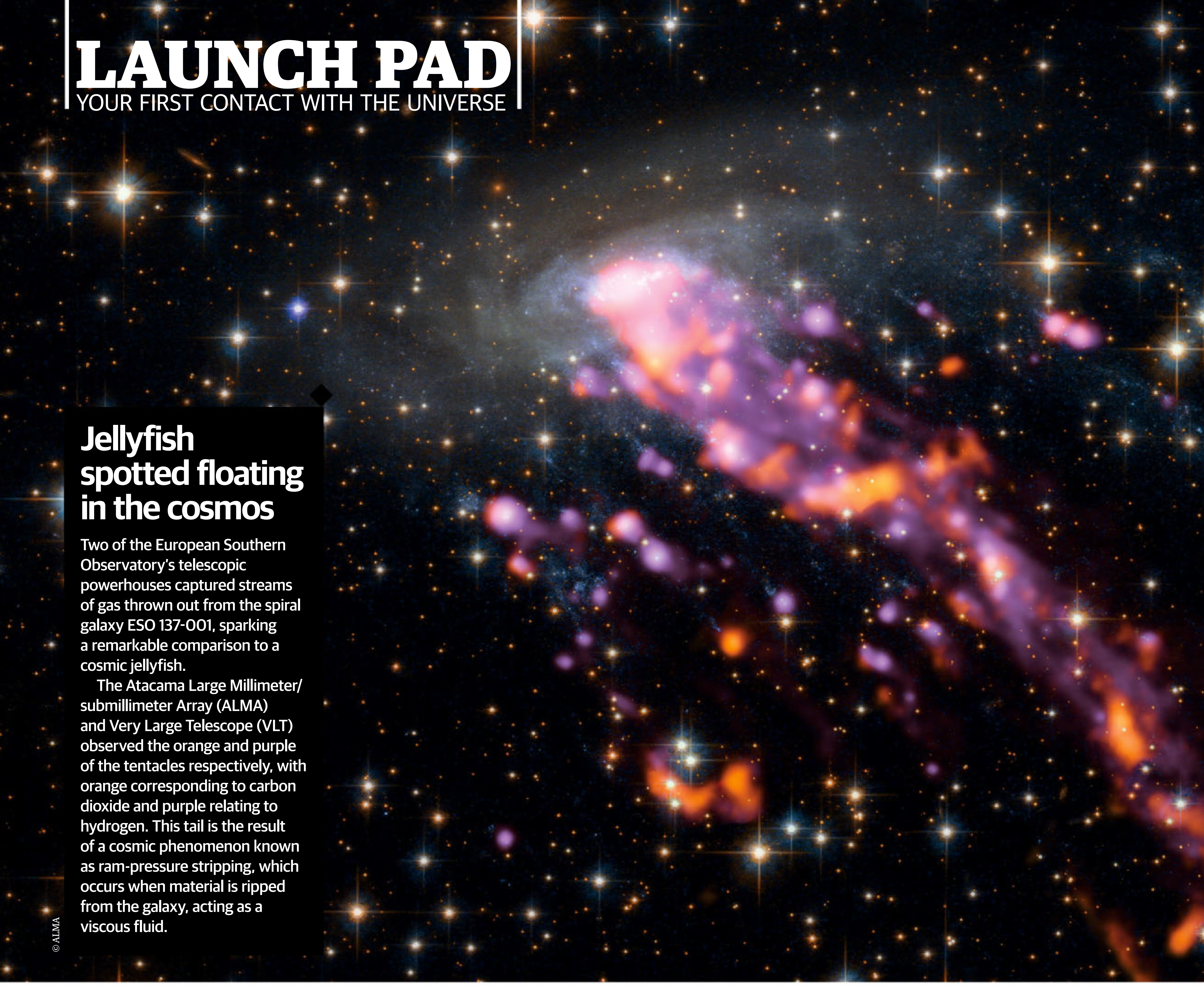

Jellyfish spotted floating in the cosmos

Two of the European Southern Observatory's telescopic powerhouses captured streams of gas thrown out from the spiral galaxy ESO 137-001, sparking a remarkable comparison to a cosmic jellyfish.

The Atacama Large Millimeter/submillimeter Array (ALMA) and Very Large Telescope (VLT) observed the orange and purple of the tentacles respectively, with orange corresponding to carbon dioxide and purple relating to hydrogen. This tail is the result of a cosmic phenomenon known as ram-pressure stripping, which occurs when material is ripped from the galaxy, acting as a viscous fluid.

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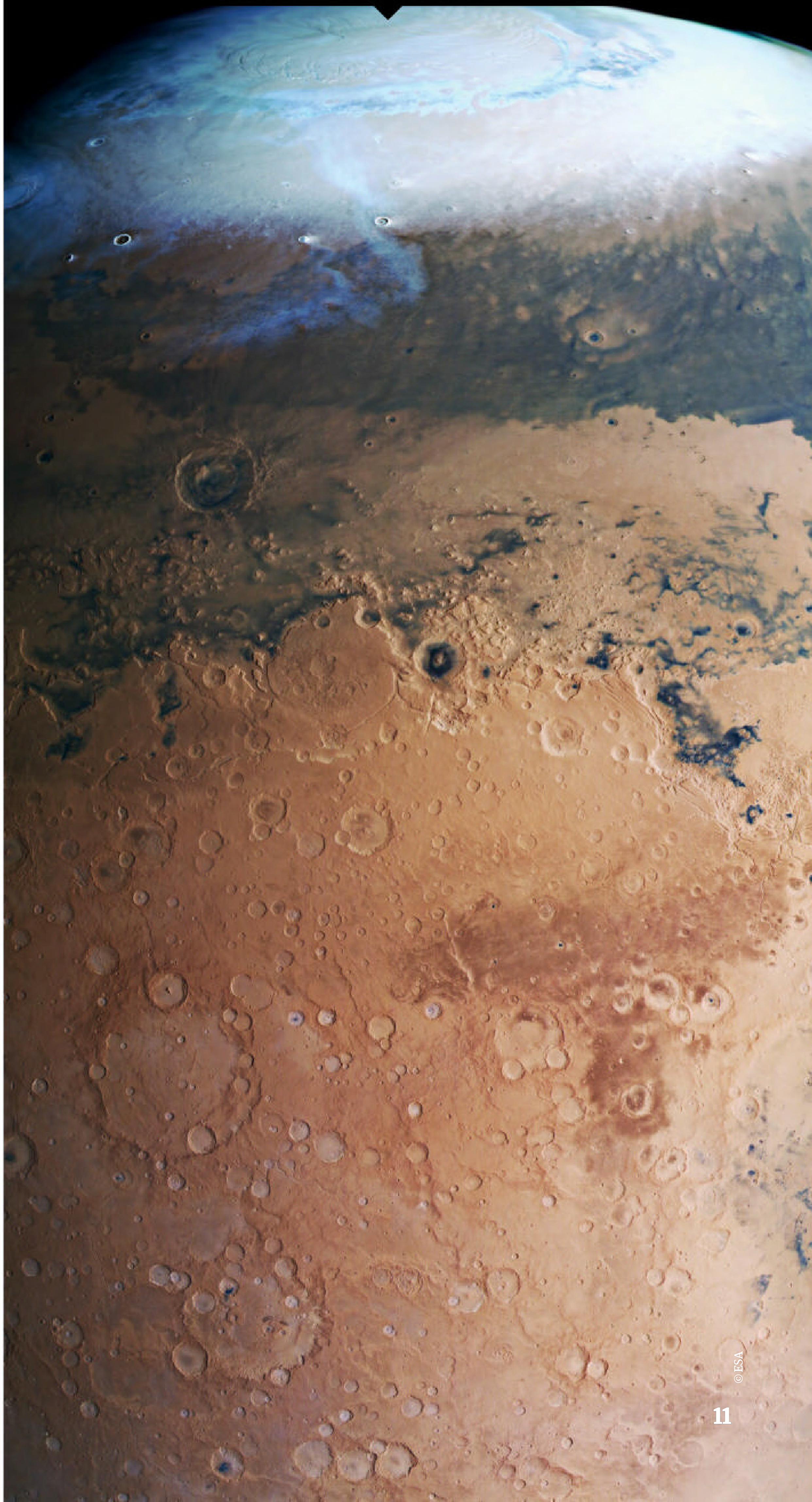
Countries and their night lights

The Iberian Peninsula is lit up beautifully at night, and was captured by one of the astronauts on board the International Space Station. Spain and Portugal are the main countries in this image, revealing how they are lit up at night, with Madrid shining brightest. Although it is a beautiful view from above, this image showcases the problem with light pollution – it becomes clear how limited some are when it comes to experiencing the thrilling sight of a night sky untouched by an artificial glow.

A slice of Red Planet

The European Space Agency's Mars Express satellite has beamed back excellent close-up images of the Martian surface over the years, and here is another one to add to the collection. This long slice of Mars shows the north pole's ice caps, and moving south there are craters and scars scattered over the Terra Sabaea and Arabia Terra regions. These close-up images can be taken for granted, but it is important to realise that at the centre of this image, a pixel equates to just one kilometre (0.6 miles) – an incredible capability for a spacecraft that continues to reveal important details about the Red Planet.



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The award was split between two areas of research

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Nobel Prize honours physicists, sparks politics

Words by **Meghan Bartels**

The Nobel Prize in physics this year has gone to two very different research threads and danced around some big societal issues, even as it celebrates distinguished work.

The award was split to honour both cosmology research exploring dark matter and the discovery of planets orbiting other stars. But the Nobel Prize is awarded to individual researchers, and that's where things seem to have gotten a little sticky this year. The Nobel Prize has been political in plenty of other years as well, and it's hardly surprising that politics has again entered the arena in 2019. On both sides of the honour people have raised concerns about who was and was not recognised, and what that says about modern science.

"When we ask these kinds of questions, it's not that these people didn't deserve it, but who else aren't we talking about that might have deserved it," Kalpana Shankar, a professor of information and communication studies at University College Dublin in Ireland, told **space.com**. "Often people who should get credit for it haven't, and Nobels and other major prizes are not immune to the politics of that."

This year's Nobel Prize in physics is a little strange from first glance in that it recognises two quite different research topics. The Royal Swedish Academy of Sciences, which awards the Nobel Prize, joined the two research threads of cosmology and exoplanets by honouring what it described as "contributions to our understanding of the evolution of the universe and Earth's place in the cosmos." It's poetic, but it's perhaps not what you would expect from the Academy.

And Nobel Prizes go to individual, living scientists, not research topics. This year the award was presented with one half of the purse going to Jim Peebles, a cosmologist at Princeton University who has studied dark matter, and the other half being split between Michel Mayor and Didier Queloz, two astronomers based at the University of Geneva and the University of Cambridge in the UK who discovered the first exoplanet orbiting a Sun-like star.

Peebles began his research on theoretical physical cosmology in the mid-1960s, searching for clues to what shaped the universe right after the Big Bang. He found those clues in the cosmic microwave background – often nicknamed the baby picture of the universe – which shows small spatial differences in temperature.

The Academy puts together a scientific background paper exploring the members' reasoning for the award. In this year's document the committee wrote that a 1965 paper Peebles wrote positing that dark matter is necessary for galaxy formation marked "the moment when cosmology embarks on its way to become a science of precision and a tool to discover new physics".

Scientists who have been exploring the concepts typically called dark matter and dark energy – two mysterious phenomena that make up the vast majority of the universe – have been on bettors' lists for the Nobel in physics for years.

But the name most frequently suggested was that of Vera Rubin, an astronomer who died in 2016 and whose work is referenced once in the scientific background paper's exploration of Peebles' work.

For years prior to her death, Nobel pundits chalked up the omission to the committee's tendency to favour experimental research over theoretical work, but this year theory seems to have triumphed, and that contrast is striking.

"While I hope to have a long, distinguished career like Jim Peebles has had, it's a shame that the Nobel Prize committee brazenly refused to give Vera Rubin the prize for finding the first concrete evidence of dark matter, and now she's dead and ineligible to receive it forever," Chanda Prescod-Weinstein, an astrophysicist and women's studies professor at the University of New Hampshire, told **space.com**.

"Meanwhile, the men who led the team that discovered cosmic acceleration, often referred to as 'dark energy', won it years ago, while she was still alive," Prescod-Weinstein continued. "The bar for women to receive the prize in cosmology and particle physics seems almost infinitely higher than it is for men."

© Spacebit

The four-legged rover will explore the lunar surface

United Kingdom's first Moon rover to launch in 2021

Words by **Mike Wall**

The UK is set to make its own giant leap soon, with a very small rover. A four-legged robot built by London-based Spacebit will launch aboard Astrobotic's Peregrine Moon lander in July of 2021, representatives of both companies announced recently.

It will be a flight of firsts – the first mission for both Peregrine and its rocket, United Launch Alliance's new Vulcan Centaur; the first trip to the Moon's surface by a UK-built craft and the first time a legged robot has explored another world.

"We could not be more excited to fly this mission with Astrobotic," Spacebit CEO Pavlo Tanasyuk said in a statement late last month. "This mission will result in the first payload from the UK to reach the Moon's surface and mark the beginning of a new era in commercial space exploration for Britain."

The rover will move at least ten metres (33 metres) on the lunar surface and will beam high-definition video and other data home to its handlers during its ten-day mission, Spacebit representatives said.

And this mission will be just the beginning, if all goes according to plan. Eventually Spacebit aims to launch a fleet of these little robots to explore the lunar subsurface and near subsurface – especially lava tubes that would be a good place for a human settlement, company officials have said.

Spacebit has other ambitions as well, as its website makes clear: "Our main goal is to democratise access to space by tokenising all of our commercial space missions around the Earth, the Moon and beyond. By decentralising our missions, we also enable citizens to directly take part in or benefit from space programmes."

Churning 'molten blob' of planet much easier to find

Words by **Meghan Bartels**

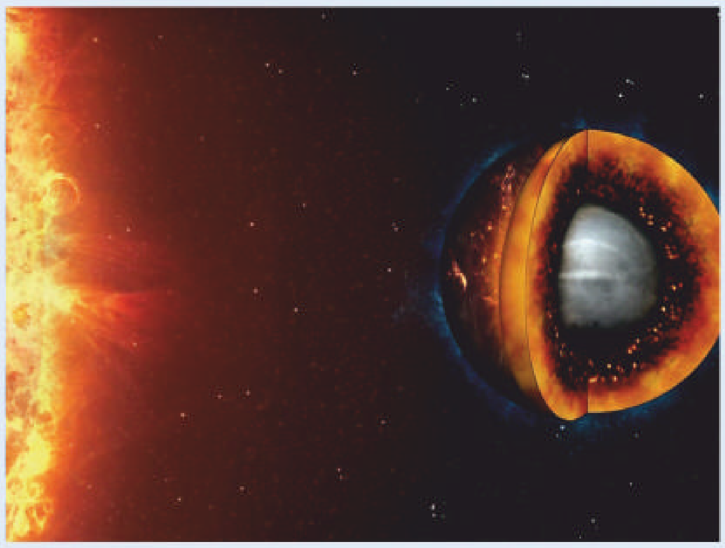
The smaller a planet, the more difficult it is to spot – which is frustrating for scientists hoping to find Earth-like worlds. That's why a team of researchers set out to determine what planetary traits would make a world a little easier to identify. Their analysis suggests that molten worlds with atmospheres full of water or carbon dioxide will be more easily observed by instruments that will be available to scientists soon.

"A rocky planet that is hot, molten and possibly harbouring a large outgassed atmosphere ticks all the boxes," Dan Bower, lead author on the new study and an astrophysicist at the University of Bern, said in a statement. "Granted, you wouldn't want to vacation on one of these planets, but they are important to study since many if not all rocky planets begin their life as molten blobs, yet eventually some may become habitable like Earth."

And that's a boon for observers: if two planets have the same mass but one has a magma ocean and the other doesn't, it could be about five per cent larger across, making it easier to spot. And a molten world is more likely to be leaking water and carbon dioxide from that liquid rock out into a developing atmosphere.

Those two molecules are easily released by molten rock, but they are also the sort of thing that future telescopes like NASA's James Webb Space Telescope are being designed to detect. Webb won't be able to study Earth-sized planets around stars like our Sun, but it should be able to analyse those around smaller M-dwarf stars.

Similarly, the slightly larger size of these molten planets won't help the struggles of finding planets orbiting Sun-like stars. But the European Space Agency's CHEOPS exoplanet-hunting mission, which is due to launch late this year, should be able to measure differences in size at that scale around M-dwarf stars.



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The hot, giant planet is speeding around its host star

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Most extreme planet completes one orbit every 18 hours

Words by **Charles Q. Choi**

Giant alien worlds known as hot Jupiters get scorchingly close to their host stars, and now astronomers have discovered the most extreme version of such a planet to date - one that zips around its star in a little more than 18 hours. This exoplanet's orbit is likely decaying enough for scientists to actually measure it over the coming decade, researchers added.

"A hot Jupiter is a large Jupiter-like planet which orbits its star on timescales less than ten days," study lead author James McCormac, an astronomer at the University of Warwick, England, told **space.com**. "In comparison Jupiter orbits the Sun with a period of approximately 12 years."

A few hot Jupiters discovered so far circle their stars closely enough to complete an orbit in less than one Earth day. The close distances between these 'ultra-short-period hot Jupiters' and their stars make such worlds ideal targets for astronomers to investigate the nature of gravitational interactions between planets and stars, much like the tidal forces between Earth and the Moon.

"Ultra-short-period hot Jupiters - those with a period less than one day - are quite rare," McCormac said.

The scientists analysed this exoplanet, dubbed NGTS-10b, using the Next Generation Transit Survey (NGTS), a robotic array of 12 telescopes at the Paranal Observatory in the Atacama Desert in Chile. "NGTS was designed to primarily discover Neptune-sized exoplanets," McCormac said. "In the process of discovering smaller planets, we are finding quite a few larger planets also."

This exoplanet orbits NGTS-10, an orange dwarf star about 70 per cent equal to the Sun in mass and diameter. The precise distance between Earth and NGTS-10 is not known yet, but the researchers expect it to be about 980 to 1,140 light years. The exoplanet NGTS-10b is a little more than 2.1-times Jupiter's mass and about 1.2-times Jupiter's diameter.

Magnetic stars have surprising origin

Words by **Charles Q. Choi**

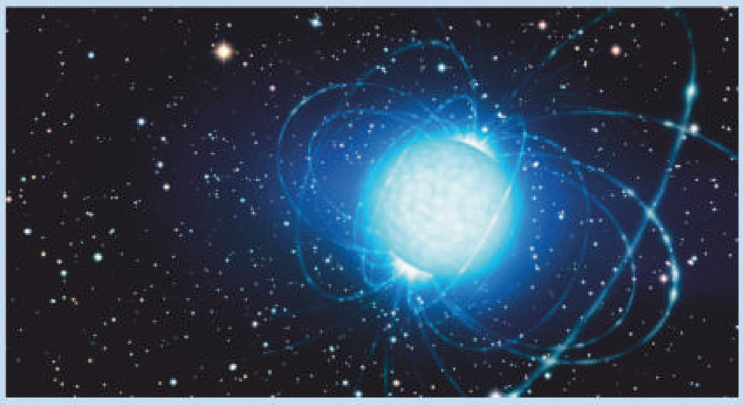
When it comes to relatively massive stars - ones more than 1.5-times the mass of the Sun - previous research found that about ten per cent have strong magnetic fields that are on average 100 to 1,000-times stronger than the Sun's. Other prior work has suggested that merged stars - ones resulting from the fusion of two other stars - could generate powerful magnetic fields, and that ten per cent of massive stars are predicted to result from mergers.

One reason merged stars are expected to possess strong magnetic fields is because, as one might expect, when two stars collide into one another, the result is a great deal of turbulence. Merged stars inherit such turbulence, and such "turbulent energy is converted into magnetic energy," said study lead author Fabian Schneider, an astrophysicist at the University of Heidelberg in Germany.

To see if merged stars might actually generate powerful magnetic fields after they settled down following the fusing together of their parent stars, Scheider and his colleagues developed 3D computer simulations of mergers between pairs of massive stars that were not magnetic and followed how the results evolved over time. Specifically they analysed mergers that were expected to result in merged stars, with each fused pair having 17-times the Sun's mass, similar to the magnetic star Tau Scorpii, located about 470 light years from Earth in the constellation Scorpius.

The simulations found that after merged stars settled back into an equilibrium state following the tumult of the mergers that created them, "strong magnetic fields are indeed produced," Schneider told **space.com**.

"Our mechanism of merging appears to be a promising way to also explain why some neutron stars may have such incredibly strong magnetic fields, supposedly the strongest in the whole universe," Schneider said.



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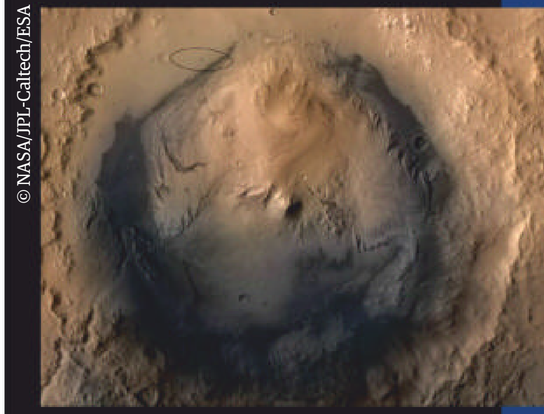

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Ancient lake on Mars turned salty for a spell, Curiosity rover finds

Words by **Mike Wall**

NASA's Curiosity rover has detected relatively high levels of sulphate salts in the rocks of Gale crater, a new study reports. Gale hosted a lake system in the ancient past, and the newfound salts were likely concentrated by evaporation during a period of low water levels, researchers said.

This period may have been part of a normal cyclical fluctuation, a regular climatic change perhaps driven by recurring shifts in Mars' axial tilt or orbital parameters. "Alternatively, a drier Gale lake might be a sign of long-term, secular global drying of Mars, posited based on orbital observations," the scientists wrote in the new study, published in the journal *Nature Geoscience* on 7 October.

It's possible that the Gale crater lake system was drying out around the time these salty deposits were laid down, lead author William Rapin, a planetary scientist at the California Institute of Technology in Pasadena, said. "Maybe habitable environments had started to become niche," he explained. "Maybe large regions of Mars were already too arid."

But there's also that other possibility - that Mars was in a temporary dry spell but would become wet again when its axis of rotation, or its orbital eccentricity, changed.

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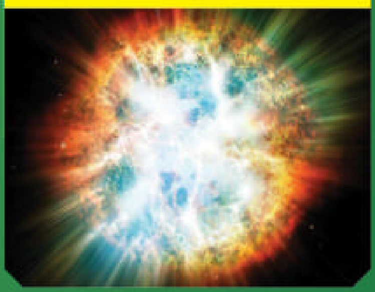

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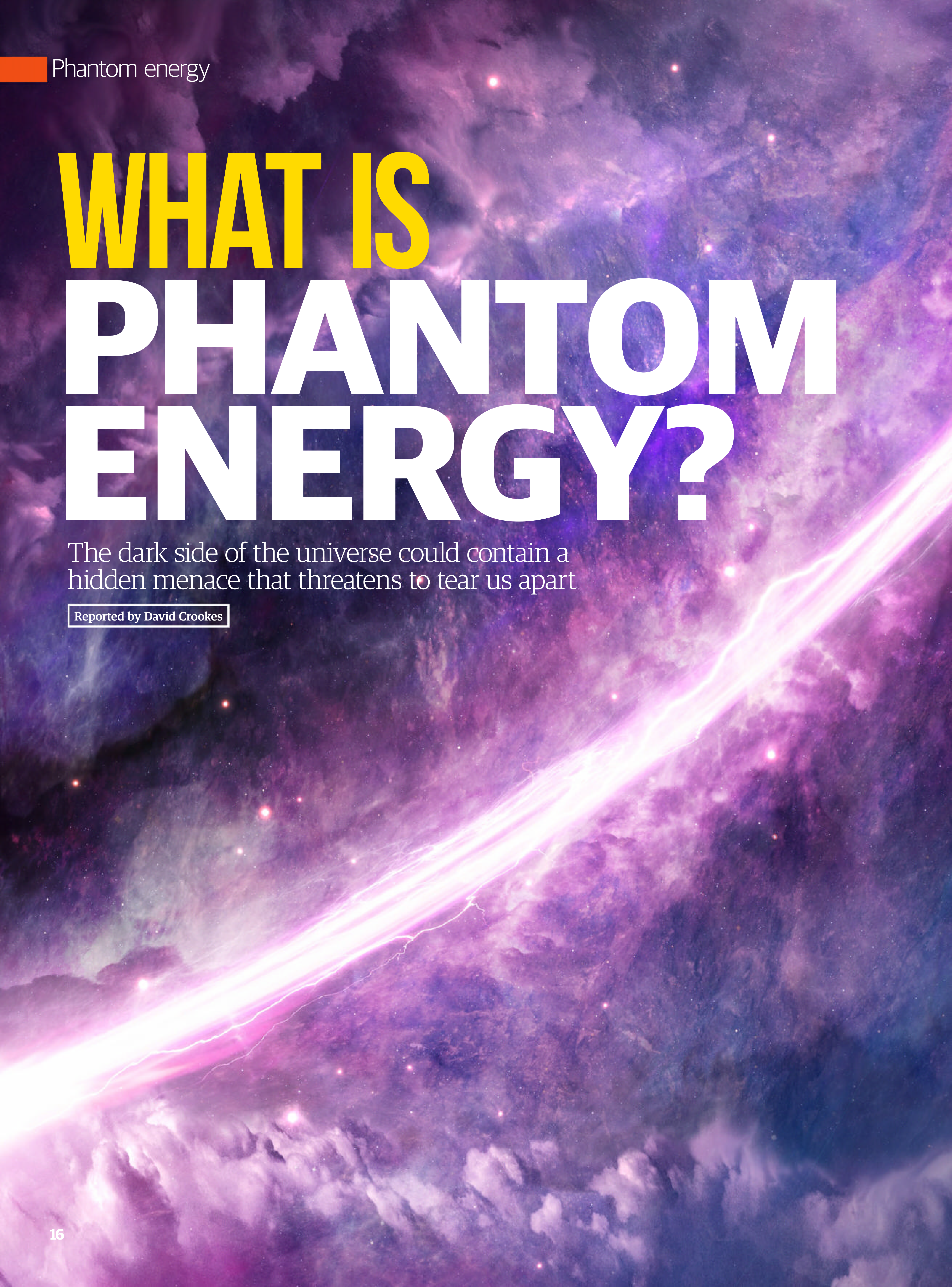
WHAT IS PHANTOM ENERGY?

The dark side of the universe could contain a hidden menace that threatens to tear us apart

Reported by David Crookes



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The end, it would seem, is nigh. Well, relatively speaking, of course. Barring a terrible human-made disaster or a cosmic catastrophe that may perhaps involve an asteroid, Earth's final moments could see it torn apart in - wait for it - 22 billion years' time. But if that is going to keep you awake at night then consider this: the entire universe will also meet a terrible end around the same period, so by current calculations we're approaching the mid-way stage of its life.

But what would cause this to happen? Scientists suggest that the universe will cease to be because of a mysterious form of dark energy that just so happens to share a name with the title of a *Star Wars* film. And while it may sound crazy, there are sound scientific principles behind what cosmologists are calling phantom energy - a theory based on the knowledge that the universe has been expanding for 13.8 billion years and that cosmic expansion is actually speeding up.

Astrophysicists discovered that the universe's expansion was accelerating back in 1998 when they noticed that distant Type Ia supernovae were fainter than expected given how far they were

Phantom energy vs dark energy

Phantom energy is set to take us down a destructive route

Dark energy dilutes during expansion

If the universe expands with a constant energy density, dark energy should become diluted.

But phantom energy gets more intense

With phantom energy, the energy density is said to actually increase with time.

Phantom energy causes fast growth

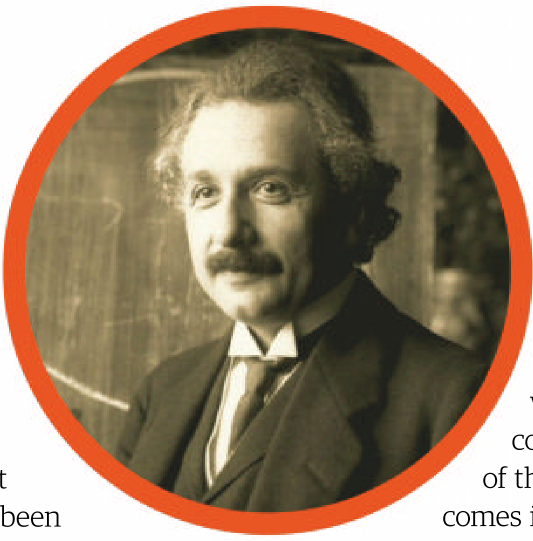
The growing density would force the universe to expand at an ever-increasing speed.

Phantom energy tears the universe apart

Since the universe expands beyond a cosmological constant, it gravitationally unbinds objects.

Dark matter won't take over

Phantom energy, however, will eventually become so strong it'll dominate other forces.



from Earth. Two teams had been looking for evidence that the universe was slowing due to gravity, as described by Albert Einstein's general theory of relativity, but the discovery pointed to the opposite being true, since it was evident that the stars had been pushed further away and the universe was expanding faster than before.

By way of explanation the scientists said the acceleration was likely due to an anti-gravitational force that became known as dark energy. This comprises roughly 68 per cent of the universe's mass-energy, and it was one of the greatest scientific discoveries of all time, showing that gravity was not the only force exerting an effect on the motion of the universe.

"The current observational data suggests that dark energy is either decaying, constant or growing - we are right near a knife edge," explains physicist Robert R. Caldwell of Dartmouth College, New Hampshire. "The best data comes from measurements of the rate of expansion over the last five or so billion years, using type Ia supernovae - known as standard candles - and baryon acoustic oscillation - standard rulers - although a change in dark energy is really difficult to quantify with precision."

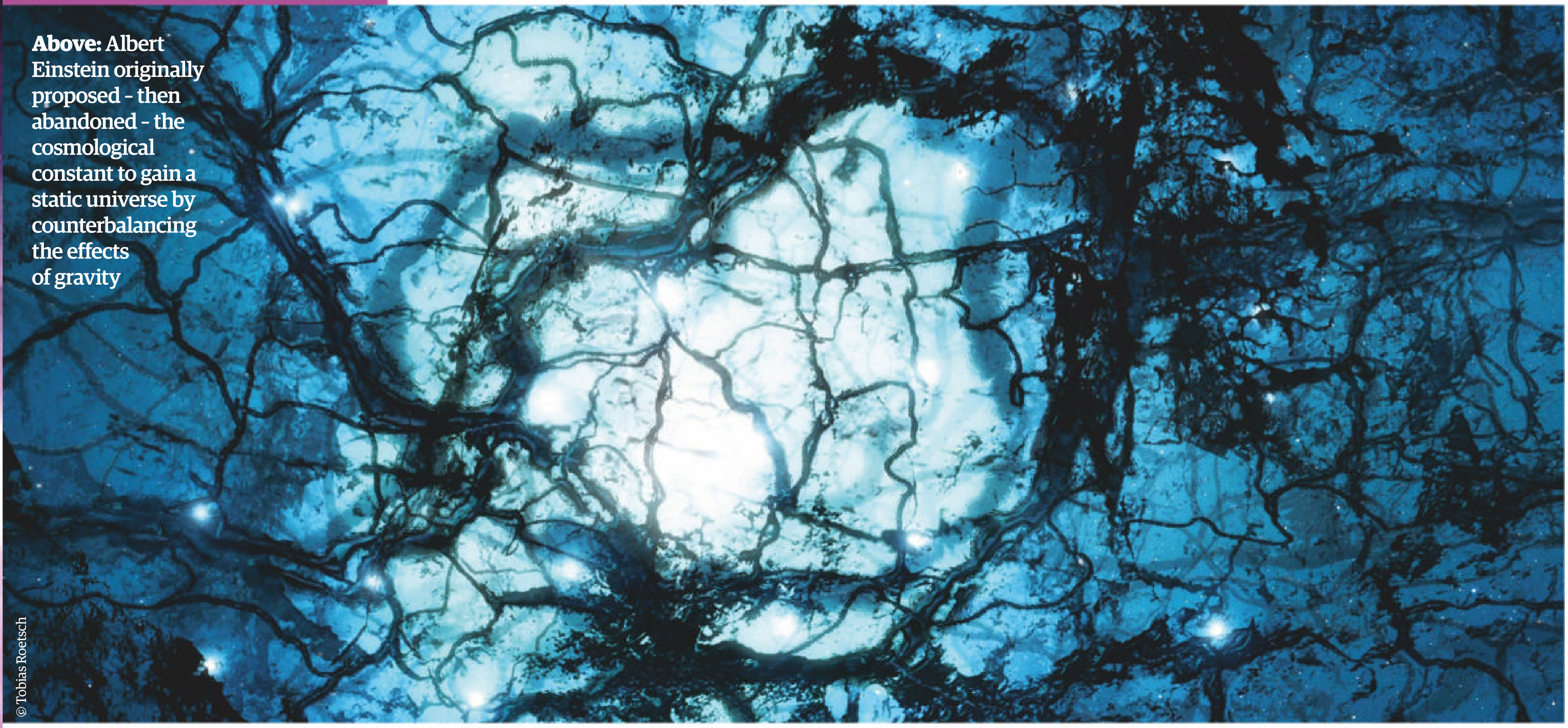
In order for it to have an accelerating effect, the amount of dark energy would need to increase as the universe expands. It would need to be created without a subsequent increase in matter so that gravity does not increase, allowing the cosmic growth rate to accelerate gradually and steadily. Indeed, in its most simple of forms dark energy would be a 'cosmological constant': the greater the volume of the universe, the more dark energy comes into existence in order to keep pace - but the strength of the energy does not change. Any energy lost is compensated by the extra space.

The concept of a cosmological constant - in the sense that a force is working against gravity - is not new. It was actually devised by Einstein as a fudge when he struggled to accept that his equations predicted an expanded universe when at the time he believed it to be static. Einstein would later call his introduction of a cosmological constant his biggest blunder in the light of findings by Edwin Hubble in 1929 which showed the universe really was expanding. It meant Einstein's original calculations could stand without the addition of the fudge.

What Hubble showed was that most galaxies were moving away from the Milky Way and that those furthest away were moving the fastest. It led to the creation of the Hubble Constant, which correlates the distance and speed of the universe's expansion. But now that we know the universe is accelerating, there is also a use for the cosmological constant after all.

What the discovery of acceleration showed in 1998 was that the cosmological constant could have

> "The current observational data suggests that dark energy is either decaying, constant or growing" **Robert Caldwell**



Above: Albert Einstein originally proposed - then abandoned - the cosmological constant to gain a static universe by counterbalancing the effects of gravity

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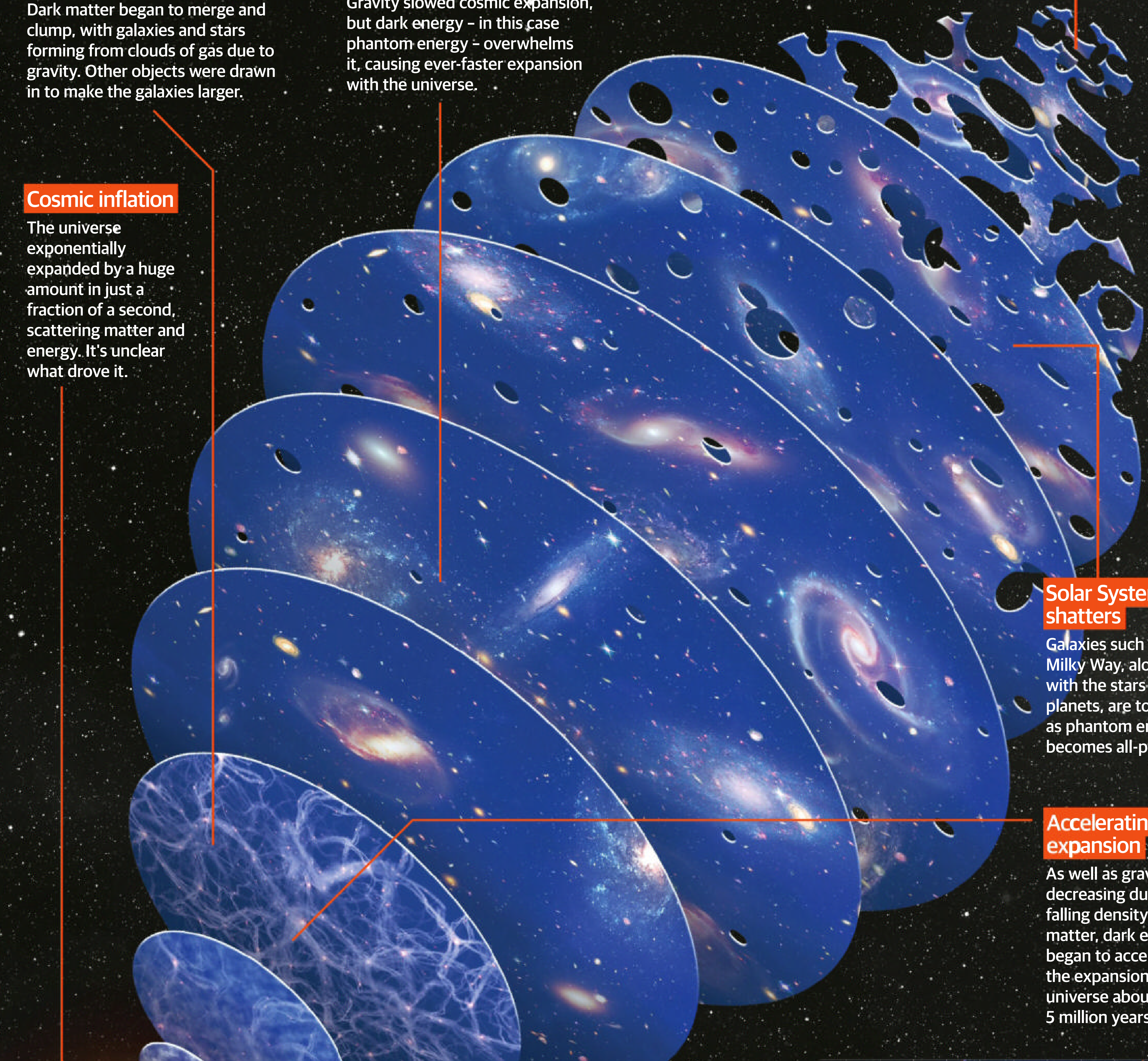
The Big Rip: how the universe could end

Phantom energy appears to be pushing the cosmos apart, and the potential result isn't pretty



Galaxy formation

Dark matter began to merge and clump, with galaxies and stars forming from clouds of gas due to gravity. Other objects were drawn in to make the galaxies larger.

Cosmic inflation

The universe exponentially expanded by a huge amount in just a fraction of a second, scattering matter and energy. It's unclear what drove it.

Ever-faster expansion

Gravity slowed cosmic expansion, but dark energy – in this case phantom energy – overwhelms it, causing ever-faster expansion with the universe.

Atoms ripped apart

Even individual atoms are eventually torn apart in the Big Rip – an event that could take place 22 billion years from now.

Solar System shatters

Galaxies such as our Milky Way, along with the stars and planets, are torn apart as phantom energy becomes all-powerful.

Accelerating expansion

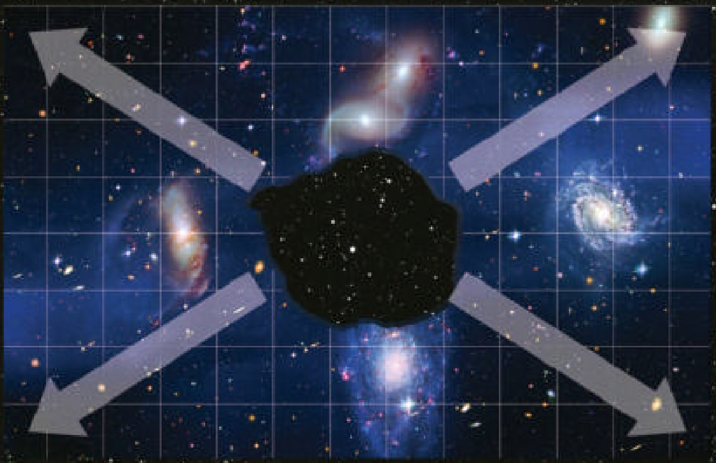
As well as gravity decreasing due to the falling density of dark matter, dark energy began to accelerate the expansion of the universe about 5 million years ago.

The Big Bang

Dark matter and dark energy are understood to have originated at the point of the Big Bang about 13.8 billion years ago.

Formation of atoms

The first atoms – mainly helium and hydrogen – were formed after some 380,000 years when electrons became trapped in orbit around nuclei.



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Above: Quintessence is a hypothetical form of dark energy that changes over time as opposed to the cosmological constant

Left: The Dark Energy Spectroscopic Instrument will be located on the Mayall Telescope and will conduct a spectrographic survey of distant galaxies to probe the universe's history of expansion

a positive non-zero value. "The universe appears to be dynamical, and so my first suspicion falls on a dynamical field, like quintessence or a phantom," Caldwell tells **All About Space**. In 2003 he said dark energy could actually grow denser and stronger within a fixed volume of space over cosmic time. Thus he coined the concept of 'phantom energy', which makes use of the cosmological constant while assuming the universe's geometry is flat. The effects are immense.

By growing stronger, phantom energy becomes more repulsive, and it pushes the universe into ever-faster and greater expansion. In terms of a cosmic 'equation of state', the ratio of the pressure-to-energy density would change, so whereas the cosmological constant would ordinarily equal minus one, which indicates the energy density and negative pressure is constant and tension exists throughout the universe, for phantom energy the equation of state will be more negative than minus one. A runaway process would ensue.

The implication is that all known matter - which decreases or remains constant over time - will lose energy by speeding up. The more the universe expands due to phantom energy, the looser the bonds would become. The visible universe - that is, the universe we can observe around us - would shrink and become so small that we wouldn't even be able to see our neighbouring galaxies as the galaxies become ever more isolated and the cosmos grows bigger and bigger. When phantom energy becomes strong enough it would overcome gravity, and that would lead to galaxy clusters being torn apart, followed by galaxies, stars, planets, moons and so on right down to the atoms in the final billionth of a second.

"The simplest theory of phantom energy does not look like the types of forces or fields we see in the Standard Model or in other phenomena in nature," Caldwell continues. "There is a nice analogy that says the dynamics of quintessence or even the Higgs field are like a ball rolling downhill. Well, according to phantom energy the ball rolls uphill. From that perspective I would need very strong observational evidence to convince me that phantom energy is at work. However, dark energy that appears like phantom energy could be the by-product of new gravitational physics, new physics of dark matter or some basic misunderstanding in our foundations. I think we need to keep the phantom energy option open until we really understand cosmic acceleration."

"I think we need to keep the phantom energy option open until we really understand cosmic acceleration" Robert Caldwell

Should the expected effects of phantom energy play out, the resulting violence would represent a rather dramatic end to the universe. The Milky Way would have been destroyed 60 million years before what is called the Big Rip, with the Solar System tearing apart with three months to go and the Earth exploding in the final 30 minutes - so there's no chance of any humans witnessing that final flourish. Of course, the suggestion that it would cause such an expansion to an infinite size in a finite time at a rate that surpasses the speed of light is all hypothetical, as Caldwell freely admits, but the evidence is nonetheless compelling, and it hasn't been entirely ruled out as a concept.

Indeed, phantom energy fits in with Einstein's theory because it's the universe which is expanding, rather than the particles it contains. It is also a special case of quintessence, another form of dark energy which has been hypothesised on the back of the universe's accelerating rate of expansion. Unlike the cosmological constant, and as we've seen with phantom energy, quintessence varies across space-time, and physicists say it is a fifth fundamental force. Depending on the ratio of its kinetic and potential energy, quintessence can be attractive as well as repulsive.

So are there any problems? A couple of years after Caldwell put forward his theory about phantom energy, scientists at the Institute for Nuclear Research of the Russian Academy of Sciences pondered the question of how the Big Rip could tear apart a black hole. Vyacheslav Dokuchaev and his team rolled up their sleeves and began to formulate some calculations before showing that phantom energy would fall into a black hole and eventually cause its mass to become smaller until the point that it disappears.

Under this scenario, the contents of the black hole are essentially dissolved. "Our calculations show that the more phantom energy falls into the black hole, the smaller its mass becomes until, just before the Big Rip, it will disappear completely," said Dokuchaev at the time. He also said a Big Rip was likely in 14 billion years time. The universe really could be in the midst of a mid-life crisis.

Or is it? Astronomers from Johns Hopkins University say the energy field causing the acceleration may be switching on and off. For example, there was rapid expansion within a fraction of a second of the Big Bang. A cosmic anti-gravity is then thought to have burst into life when the universe was 100,000 years old, only to turn off 100,000 years later, leaving an accelerated universe as evidence that this took place.

With this early dark energy in mind there has been an attempt to tweak the model of the early universe, perhaps by adding more

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Left: Our galaxy would be destroyed millions of years before the Big Rip

Below: Quasars can be used to measure the expansion of the universe by studying their X-ray and ultraviolet data

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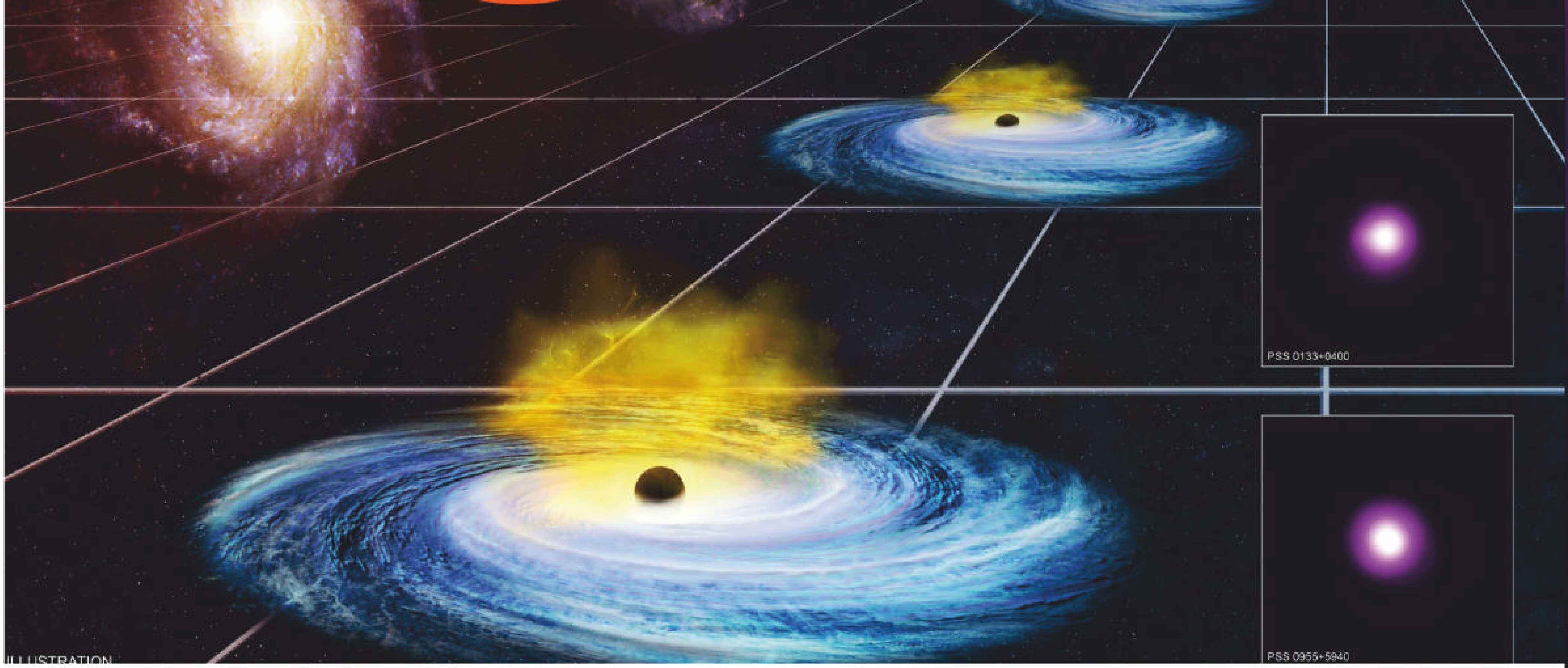
Missing link: early dark energy

There may be an exotic form of dark energy lurking in the universe, and it could explain a stubborn discrepancy in measurements of the universe's expansion rate.

This so-called early dark energy might have existed in the universe's infancy, then flickered out of existence soon after. That, in turn, would explain why expansion rates disagree.

During the past two decades, scientists who study the universe's accelerating expansion have found two very different rates. The universes' first light — the cosmic microwave background radiation or CMB — suggests a lower rate for the expansion of space than do studies of supernovas and pulsating stars in the nearby universe. In other words, the universe seems to be expanding faster now than would be predicted by how it looked in the early history, shortly after the Big Bang.

This disagreement has been termed the "Hubble tension." Because the the CMB rate is at odds with other estimates, and since its calculation relies on cosmological models, it's thought that something must be missing from the model — such as new laws of physics or unknown types of matter.



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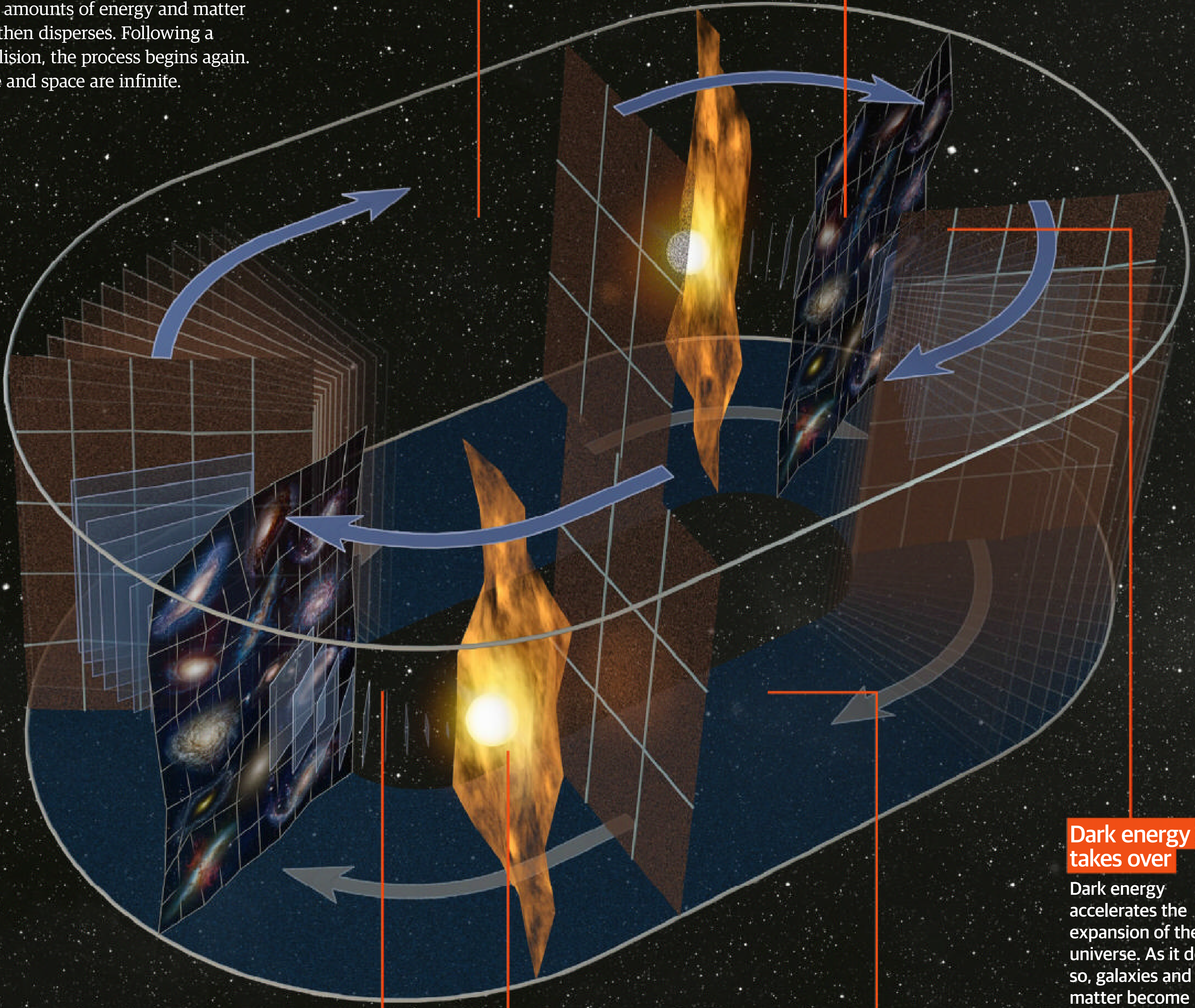
The cyclic universe

How the universe may be dying and springing back to life forever more

The idea that the universe has gone through a process of expansion and contraction over and over again is not new, but the cyclic universe model by Paul Steinhardt and Neil Turok is nevertheless intriguing. It involves the observable universe residing in a higher-dimensional void, colliding with a mirror version and unleashing huge amounts of energy and matter that then disperses. Following a recollision, the process begins again. Time and space are infinite.



The big collision

The model posits that two parallel orbifold planes – called M-branes – are connected via gravity, and that at some point they collide. This creates the Big Bang.

Moving apart

Following the Big Bang the M-branes rebound, reach maximum separation and the universe cools. There is a prolonged period of expansion, during which time the galaxies form.

Dark energy takes over

Dark energy accelerates the expansion of the universe. As it does so, galaxies and matter become more and more spread out.

Another collision

The branes collide once again and repeat the process. It means we would be in just one of many cycles and that the universe pre-dates each Big Bang.

A trillion years later…

Now that the branes are empty and flat, the branes begin to contract once more. This happens some trillion years after the Big Bang.

Era of darkness

Having gone from hot to cold, dense to under-dense and from a period of hot radiation, the universe eventually becomes empty.

©Nicholas Forder

neutrinos to the universe in its earlier years so that more energy can be stored and invigorated. It works on the assumption that quintessence could spring into life, decay or change from repulsive to attractive, so there is every chance that the acceleration we are witnessing today will be temporary. Evidence, however, continues to mount that dark energy is increasing.

Guido Risaliti of the University of Florence in Italy and Elisabeta Lusso from Durham University have been studying quasars - the hottest and brightest cores of distant galaxies - which has allowed them to measure the expansion of the universe up to 12 billion years ago. "Using quasars as standard candles has great potential since we can observe them out to much greater distances from us than Type Ia supernovae, and so use them to probe much earlier epochs in the history of the cosmos," Lusso is quoted as saying.

With X-ray data from more than 7,000 quasars combined with ultraviolet observations - the ratio of which is dependent on the ultraviolet luminosity - the scientists noted again that dark energy is increasing over cosmic time, and so the results rule out the cosmological constant. The pitfall of using quasars is that they are not standard candles in the sense that they can evolve themselves over time, but by cross-checking their results with those derived from Type 1a supernovae, there was great similarity, putting the study on firmer ground.

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There is, however, a further complication. Jamie Farnes, a research associate and astrophysicist from the University of Oxford, has suggested dark matter and dark energy are not separate, but part of a “single, unified dark fluid of negative masses” spread across the universe. The theory modifies Einstein's general theory of relativity and assumes different expansion rates in different directions, as well as the existence of negative masses. This fluid is also said to self-create.

“We now think that both dark matter and dark energy can be unified into a fluid which possesses a type of 'negative gravity', repelling all other material around them,” Farnes said in a press statement. “Although this matter is peculiar to us, it suggests that our cosmos is symmetrical in both positive and negative qualities.”

Although the theory of dark fluid has been questioned by other scientists, it certainly doesn't rule out phantom energy. “A growing dark energy, also known as phantom, can be described in terms of either a field or a dark fluid,” Caldwell tells us. “A dark fluid relies on a more phenomenological description of the physics of phantom energy than a scalar field does. Consequently, a dark fluid can evade some of the instabilities that are inherent in a scalar field description.”

In fact, Caldwell adds: “The dark fluid description is a way around the instabilities and provides a pathway to a deeper understanding of phantom energy, if the evidence points that way.” Of course it is still far from conclusive, and the idea of phantom energy - and indeed dark energy as a whole - will continue to puzzle astronomers.

“We need more precise measurements of the expansion history over the last five or so billion years, since the presumed onset of dark energy,” Caldwell tells us. “There is more capacity for improvement from the reliable methods we’ve used so far - standard candles and standard rulers. I am strongly optimistic that dedicated projects like the Dark Energy Spectroscopic Instrument, the forthcoming space telescope Euclid, the Large Synoptic Survey Telescope and the Wide Field Infrared Survey Telescope are going to refine our understanding very soon.”

> “Using quasars as standard candles has great potential, since we can observe them out to much greater distances” **Elisabeta Lusso**

Above: A growing dark energy can be described in terms of either a field or a dark fluid

Below: According to Vyacheslav Dokuchaev, phantom energy would dissolve a black hole rather than tearing it apart

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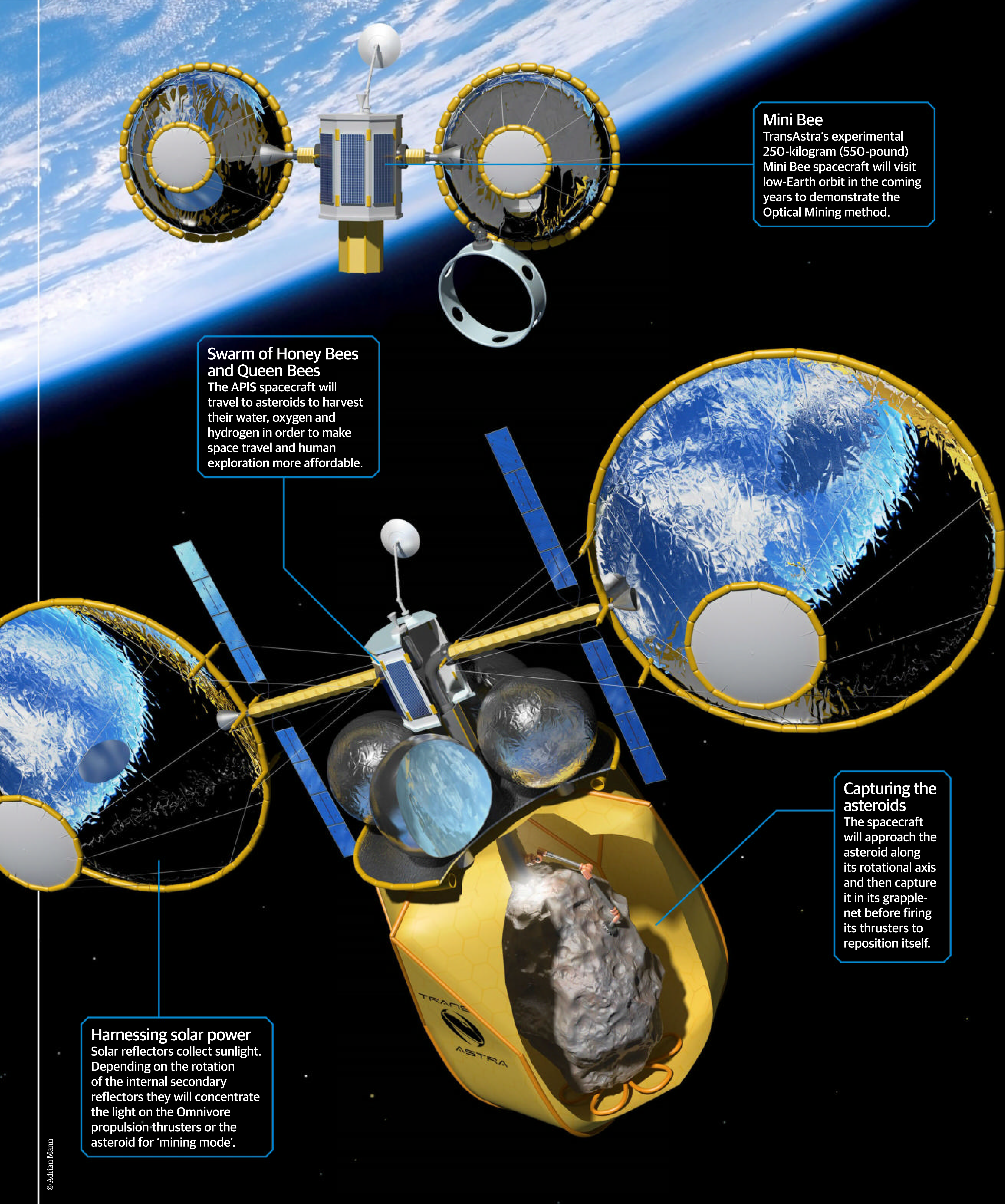

Mini Bee
TransAstra's experimental 250-kilogram (550-pound) Mini Bee spacecraft will visit low-Earth orbit in the coming years to demonstrate the Optical Mining method.

Swarm of Honey Bees and Queen Bees
The APIS spacecraft will travel to asteroids to harvest their water, oxygen and hydrogen in order to make space travel and human exploration more affordable.

Capturing the asteroids
The spacecraft will approach the asteroid along its rotational axis and then capture it in its grapple-net before firing its thrusters to reposition itself.

Harnessing solar power
Solar reflectors collect sunlight. Depending on the rotation of the internal secondary reflectors they will concentrate the light on the Omnivore propulsion thrusters or the asteroid for 'mining mode'.

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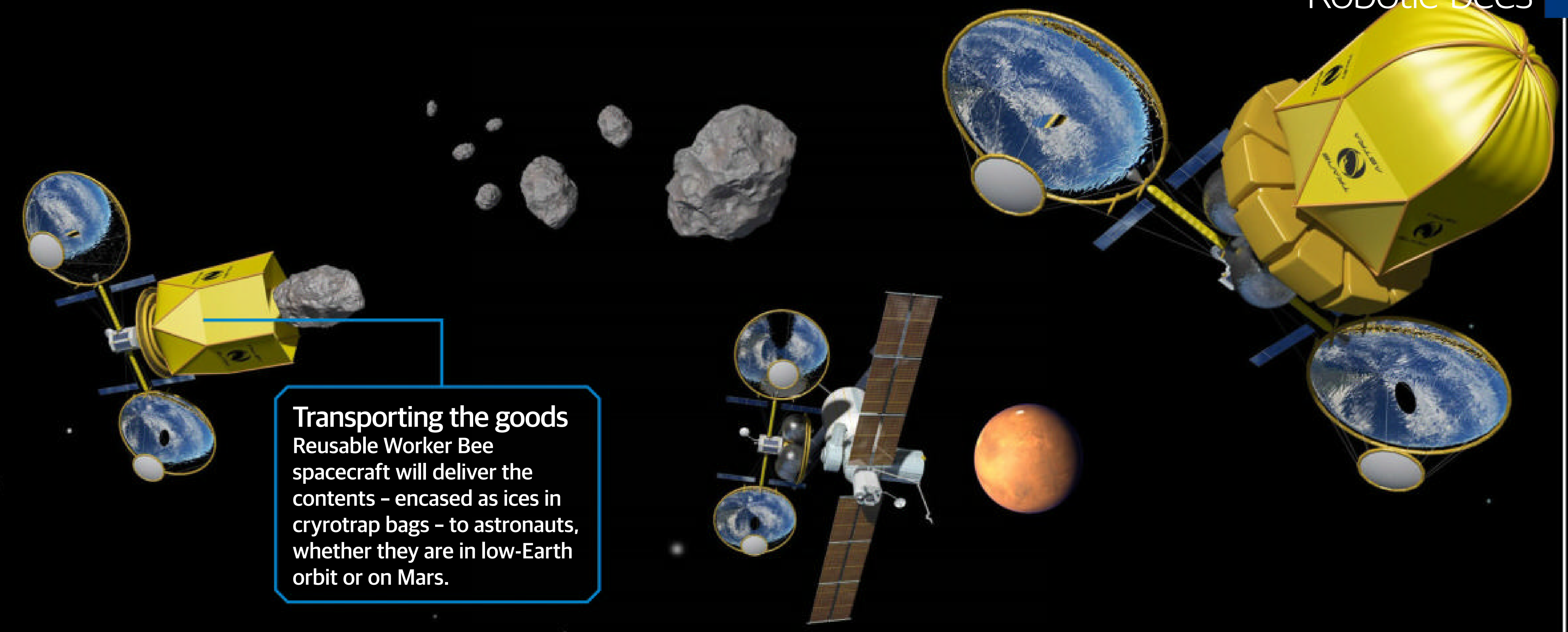


Transporting the goods
Reusable Worker Bee spacecraft will deliver the contents – encased as ices in cryrotrap bags – to astronauts, whether they are in low-Earth orbit or on Mars.

ROBOTIC ASTEROID-MINING BEES

TransAstra Corporation's APIS family of spacecraft could soon be mining asteroids to aid interplanetary travel

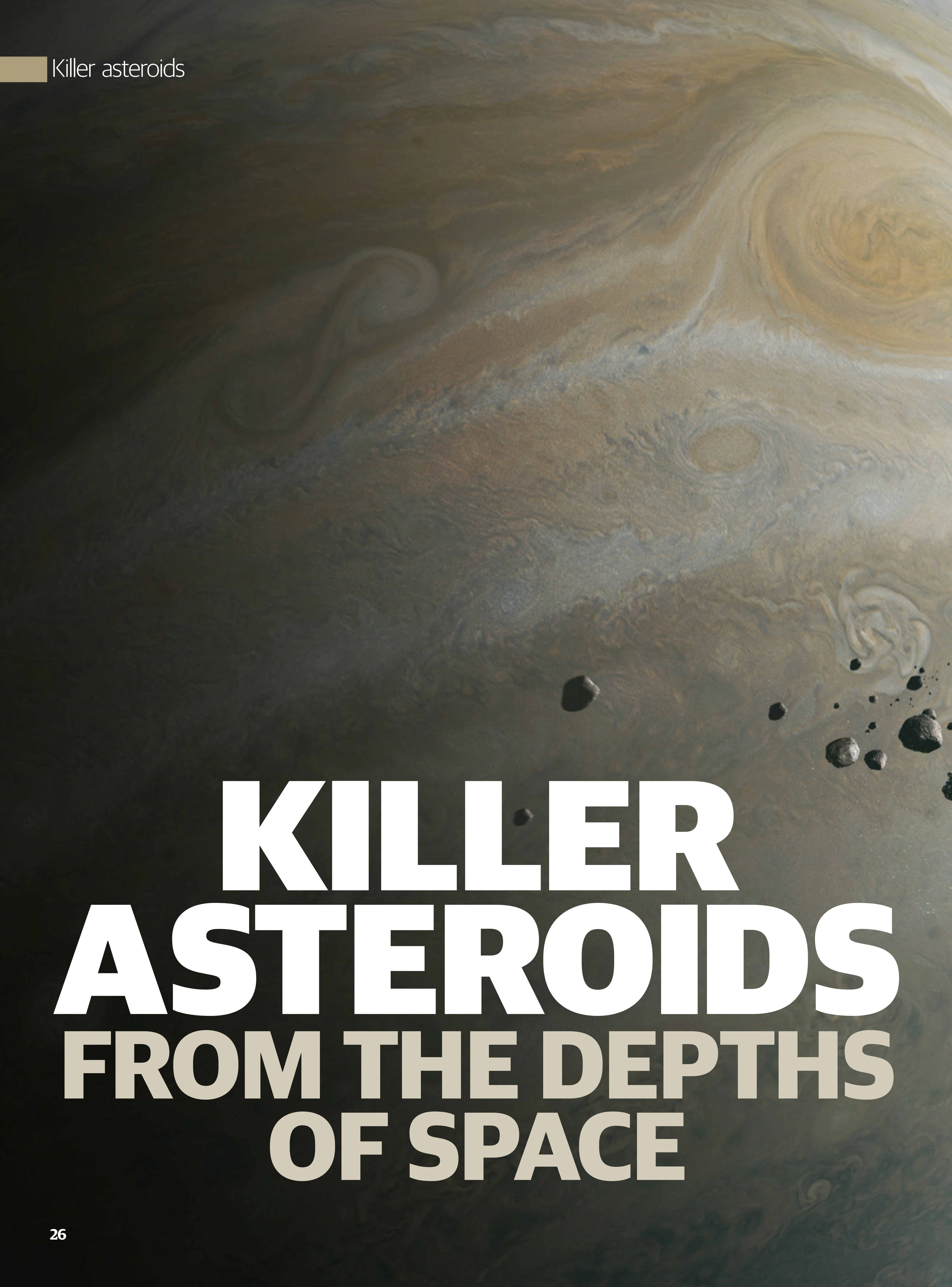
NASA is always on the lookout for ideas that are out of the box, never mind out of this world. In the search for the next creative breakthrough the NASA Innovative Advanced Concepts (NIAC) Program green-lit an asteroid-mining concept to commence with its third phase. The TransAstra Mini Bees could potentially revolutionise sustainable and affordable space travel by 'Optical Mining' any near-Earth objects, particularly carbonaceous chondrite asteroids.

Optical Mining is not to be confused with Earth mining – it doesn't involve astronauts being launched to asteroids with a pickaxe and shovel. Instead, NASA has invested in the development of a Mini Bee prototype spacecraft, part of the broader Asteroid Provided In-situ Supplies (APIS) family of spacecraft lead by Joel Sercel at TransAstra Corporation in Los Angeles, California. These spacecraft – with the Mini Bee the main priority at the moment – would capture asteroids and use highly concentrated sunlight to excavate and harvest the contents within, which could then be used for space travel and space colonisation. The main desirable materials include water, oxygen, rocket propellant and habitat-building materials. This would save the space agency billions of dollars, as instead of launching these substances into space from Earth, the material would already be there.

Phase one of the mission yielded fantastic results, having tested a full-scale eight kilowatt Optical Mining demonstration in a vacuum using concentrated light. Based on this examination the TransAstra team stated that this has the potential to save up to £8 billion ($10 billion) a year, or £120 billion ($150 billion) over the 15-year life cycle of a human exploration mission. This money could swing the pendulum from unaffordable to affordable within Congress' budgets. With much excitement the team continued with phase two, which had them develop the APIS swarm, ranging in size but with similar architecture. The space-based optical miners include the Mini Bee, a low-Earth orbit technology demonstrator; the Honey Bee, capable of capturing a ten-metre (33-foot) asteroid and extracting resources and the 'ultimate' Queen Bee, which would be capable of capturing a 40-metre (130-foot) asteroid.

These bees would all include an asteroid-containment system, similar to the design of NASA's now-discontinued Asteroid Redirect Mission concept, which will capture asteroids and enclose them in a thin film bag. Afterwards reflectors would concentrate sunlight onto the asteroid, thus exposing its interior contents and tapping into the ancient vault of valuable resources. In order to transport the materials from a bee, there would be another addition to the swarm called the Worker Bees. They would transfer items to astronauts, whether they are in low-Earth orbit, on the Moon or even on Mars.

Now TransAstra will have £1.6 million ($2 million) from NASA to invest in the next stage of its mission over the course of the next two years. In this time it will have three major objectives: to develop a detailed mission roadmap, mature and demonstrate the new technologies – such as the Optical Mining, the asteroid capturing and excavating systems and the solar-thermal Omnivore propulsion thruster – and finally develop a Mini Bee flight prototype for real-life testing.



KILLER ASTEROIDS FROM THE DEPTHS OF SPACE

Does Jupiter shelter a reservoir of dangerous asteroids that could threaten Earth?

Reported by Giles Sparrow

Jupiter is the heavyweight of the Solar System, some 300-times more massive than Earth and with a gravitational field that influences a vast region of space. Astronomers often think of it as a guardian of the smaller rocky planets in the inner Solar System because of the way it disrupts the orbits of threatening comets – tearing them apart, or sometimes swallowing them entirely. But new research suggests Jupiter's gravity has a darker side, offering a hiding place for previously unknown asteroids and comets that could, if disrupted, bombard the vulnerable inner planets.

The new class of object, identified in recently published research by Kenta Oshima of Japan's National Astronomical Observatory, has found a different solution to the problem of coexisting with Jupiter. They are so-called 'co-orbital' objects that orbit the Sun in the same 11.9 years as Jupiter, but keep their distance from the planet itself.

Astronomers have long known about one class of co-orbital object near Jupiter. These are the 'Trojan' asteroids, rocky worlds that follow the giant planet's orbit almost exactly, but are clustered at angles 60 degrees ahead and behind Jupiter itself if measured from the Sun's point of view. This puts the Trojans at so-called 'Lagrangian points' – sweet spots where the gravitational influences of Jupiter and the Sun balance out in such a way as to permit a small body – whose own gravity has a negligible influence – to survive in a mostly stable orbit.

The Trojans are thought to have reached their current orbits early in the history of the Solar System – they may represent a surviving fragment of the vast number of small rocky and icy bodies that formed in this region of the outer Solar System but were mostly destroyed or ejected in the period when the giant planets migrated outwards.

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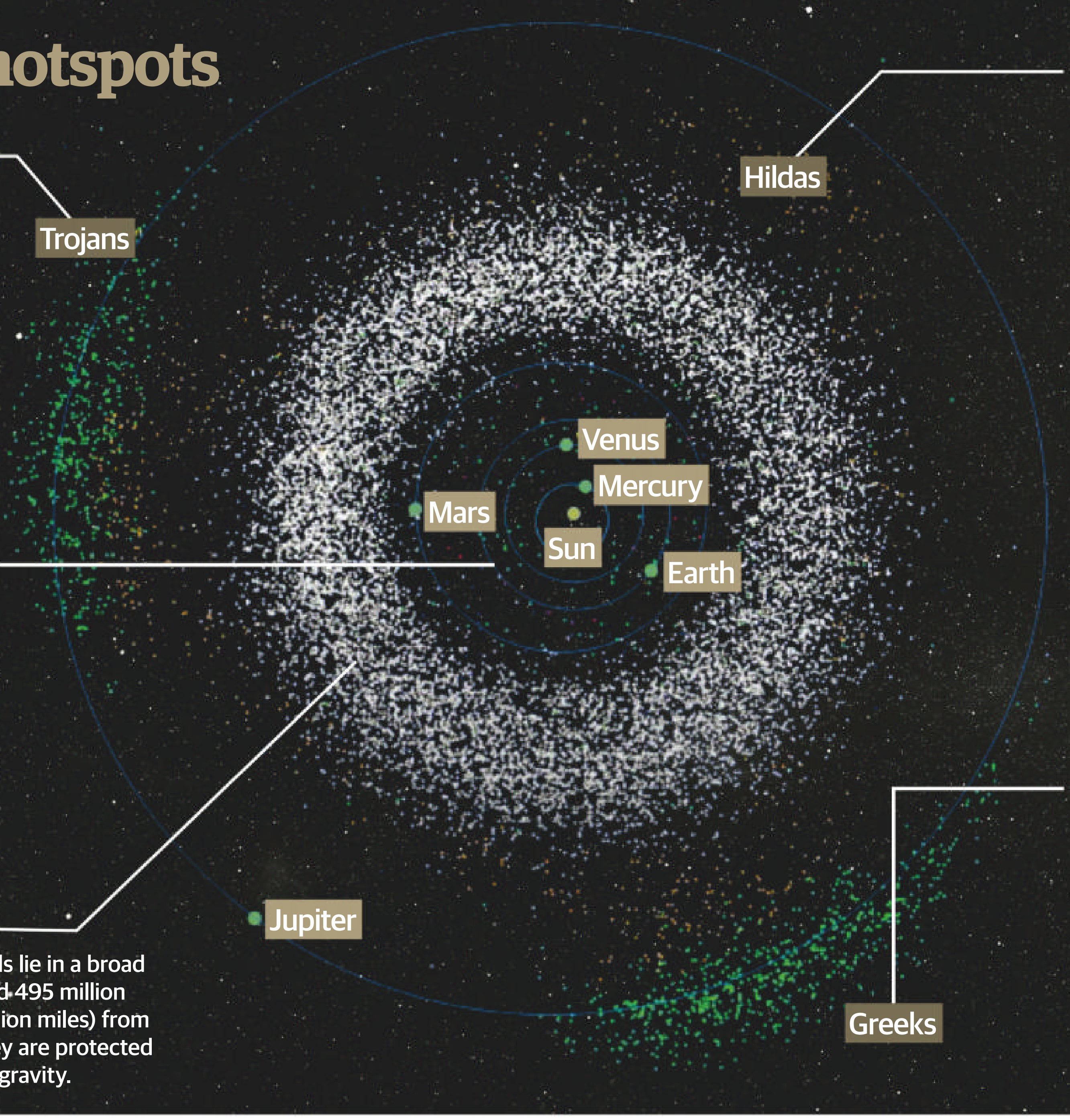
Asteroid hotspots



Trojan asteroids

The Trojans roughly follow the orbit of Jupiter itself, but stay 60 degrees behind or ahead of the giant planet. Those which trail behind Jupiter are named after characters on the Trojan side of the legendary Greek war.

Near-Earth asteroids

Collisions and close encounters in the asteroid belt eject some of its members into orbits that bring them into the inner Solar System, where they may threaten planets including Mars and Earth.

Main belt

The vast majority of asteroids lie in a broad band between about 310 and 495 million kilometres (193 and 308 million miles) from the Sun – a region where they are protected from disruption by Jupiter's gravity.

Hilda asteroids

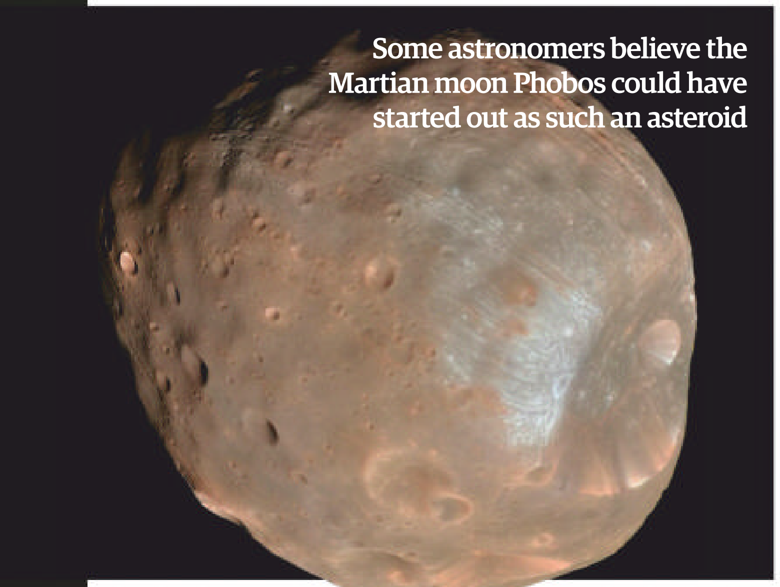
The Hilda asteroids form three distinct clumps. At the outer edge of their orbits they come close to the Trojan groups or lie directly opposite Jupiter. They move from one point on this triangle to the next with each orbit.

A new threat?

At least one asteroid, 2004 AE9, follows a complex orbit that spends much of the time close to Jupiter, but highly inclined. It sometimes becomes flatter and more elliptical in a million-year cycle.

The Greek camp

Despite their general designation as Trojans, asteroids which orbit 60 degrees ahead of Jupiter are actually named after Greek characters in the story of the Trojan war. They include the first Trojan to be discovered in 1906, asteroid 588 Achilles.



Some astronomers believe the Martian moon Phobos could have started out as such an asteroid

© NASA/JPL-Caltech/University of Arizona

In 1994 fragments of a comet previously torn apart by Jupiter smashed into the planet, leaving 'bruises' in its atmosphere

© NASA/ESA

> "If they become unstable and inclination is traded for eccentricity, the path may become planet-crossing" **Dr Carlos de la Fuente Marcos**

Another set of refugee worlds found a different and more complicated solution to avoiding Jupiter. These 'Hilda' asteroids, named after the first object of the kind to be discovered, follow elliptical orbits that bring them closer to the Sun than Jupiter at one end, but reach their outer edge in the midst of the Trojans or at another Lagrangian point on the exact opposite side of Jupiter's orbit from the planet itself. They orbit the Sun three times for every two Jupiter 'years', with their aphelia circling the Sun once every three orbits, marking out an enormous triangle in space.

Ever since they were discovered, astronomers assumed that the orbits of Jupiter's co-orbital asteroids were essentially stable, and unlikely to change, even over billions of years. But in the past decade new research has revealed a more complex picture. Because they are subject not just to the influence of Jupiter and the Sun, but also to the far weaker effects of Saturn and the risk of occasional collisions, individual orbits of asteroids in these regions are 'chaotic', in the scientific sense. This means they are constantly changing in unpredictable ways on the smallest scales, but also with the potential to evolve, relatively suddenly and unexpectedly, onto trajectories that take them far from their original paths.

A 2005 study suggested that up to 17 per cent of Trojans have orbits that are unstable over the age of the Solar System, giving them the potential to become true satellites of Jupiter itself, or fall into orbits that bring them closer to the Sun. Given their origins at the outer edge of today's main asteroid belt, these outer refugees probably contain substantial amounts of ice, which could see them develop comet-like comas and tails as they hurtle into the warmer inner Solar System. What's more, because they tend to orbit close to the main plane of the Solar System - known as the ecliptic - infalling objects ejected from the Trojans or Hildas have the potential to come close to, and even threaten, the inner planets, including Earth itself.

Oshima's work adds a whole new family of potential threats to the swarm of bodies living in Jupiter's gravitational shadow. It focuses on a completely different group of co-orbital objects –

Collisions between asteroids can disrupt their orbits or send fragments onto potentially dangerous new paths around the Sun

© NASA/JPL-Caltech

2004 AE9 was discovered by asteroid hunters based at Lowell Observatory in Arizona

© Getty

Jupiter's powerful gravity makes its presence felt

© NASA/JPL-Caltech

ones that until now were generally ignored and assumed to be harmless. These worlds orbit the Sun in the same period as the giant planet, but in orbits that are both somewhat elongated and highly inclined to the ecliptic. This means their location ranges from around the orbit of Jupiter to somewhat closer in, but they spend very little time in the plane of the Solar System, and so are unlikely to come close to other planets and asteroids.

"It's like in the case of aeroplanes," comments Dr Carlos de la Fuente Marcos of Spain's Complutense University of Madrid, another expert in Solar System dynamics who was uninvolved in the work. "Flying high above the ground, they can only crash against something while landing or taking off. But if they fly very low, the probability of running into a mountain or even a building increases significantly."

However, Oshima's work has now shown that this family of objects is also unstable. When subjected to small external forces they are prone to long-term variations that change their remote, unthreatening orbits into something with lower inclination and greater eccentricity - just the kind of orbit that could threaten the inner planets. "Objects originally moving in highly inclined but nearly circular orbits have a low probability of impact," elaborates de la Fuente Marcos. "If they become unstable and inclination is traded for eccentricity, the path may become planet-crossing with a low inclination, which translates into a higher probability of impact."

Oshima's discovery is significant because it challenges long-standing assumptions about the kind of objects likely to threaten Earth - assumptions that surveys of hazardous objects, often given the umbrella term 'Spaceguard', have generally tended to follow. "From the perspective of Spaceguard," writes Oshima, "low-inclination objects have a greater likelihood of impacting the Earth… [However], highly eccentric, highly inclined stable orbits which will reduce their inclinations in the future could be candidates for hosting populations of undetected dangerous objects."

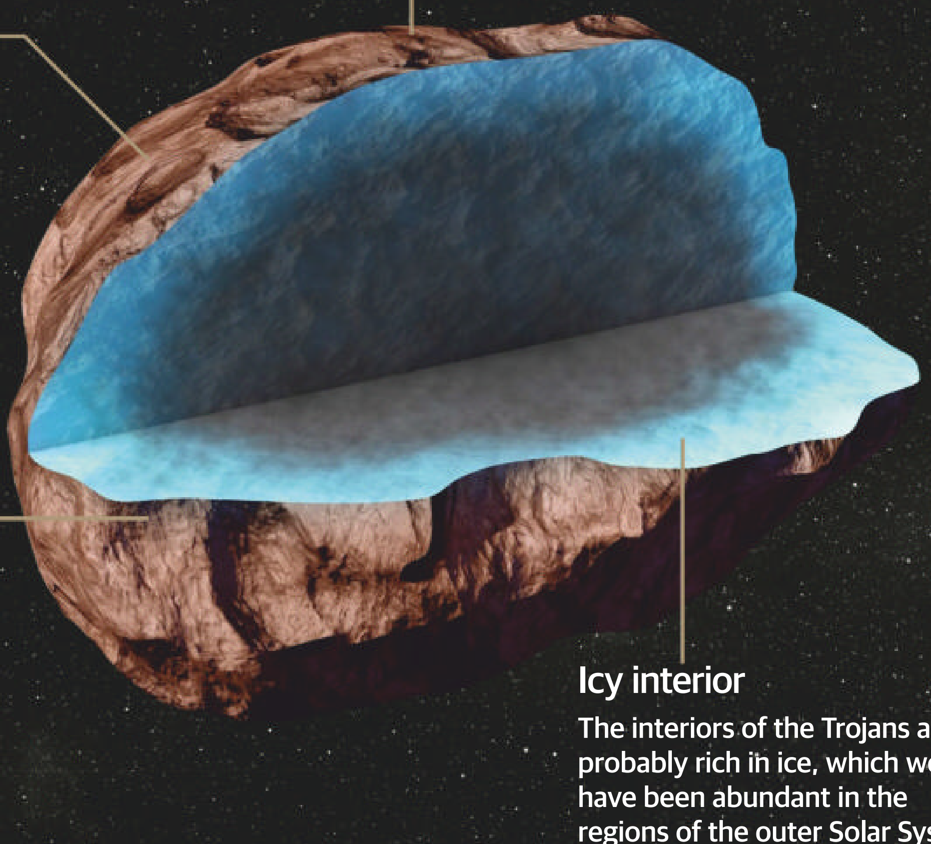
Oshima has already identified one potential member of this new family of objects, an asteroid known only as 2004 AE9. Its current orbit of 11.65 years - a little less than Jupiter's - is highly eccentric, ranging from just outside the orbit of Mars to just inside that of Jupiter. Its inclination, however, is just 1.65 degrees from the ecliptic. Oshima's colleagues have shown that this is just the low-inclination phase of an orbit that varies significantly over the long term, and while this particular world is unlikely to ever threaten Earth, it could be an important warning of others that could.

"It is worth it to keep an eye on them, particularly cataloguing them to have a census and to better know the actual size of this potentially hazardous population," argues de la Fuente Marcos. "If they are numerous, the danger could potentially be high, but if they are scarce [it] could be completely negligible."

If nothing else, Oshima's new research is a timely reminder that space hazards can come from unexpected places, and perhaps we shouldn't take the benign influence of our Solar System's biggest planet for granted.

Inside an asteroid

Take a closer look at Hektor, a Trojan from the 'Greek camp'



Reddish surface

Hektor's crust, like those of most Trojans, many outer asteroids and many comets, is dark and reddish, suggesting a surface coating of silicate minerals and complex carbon-based chemicals.

Largest Trojan

Hektor, in the 'Greek camp' of Trojans, is the largest of its asteroid family, some 403 kilometres (250 miles) long but just 201 kilometres (125 miles) wide.

Contact binary?

One popular theory to explain Hektor's shape is that it is actually a pair of asteroids that stuck together after a low-speed collision.

Icy interior

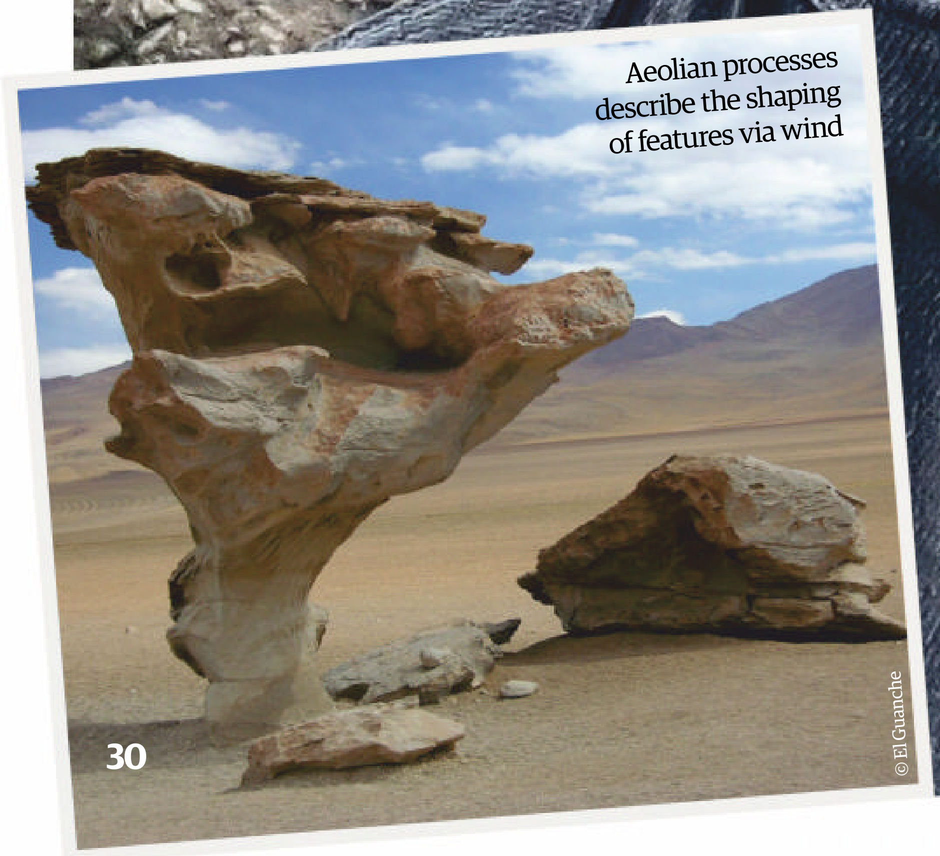
The interiors of the Trojans are probably rich in ice, which would have been abundant in the regions of the outer Solar System where they formed.

© Adrian Mann

INTERVIEW BIO

Dr Matt Balme

Balme is a senior lecturer at the Open University, based in the UK. His work is largely focused on planetary science, and more specifically planetary geomorphology. Understanding how natural processes can shape an extraterrestrial planet has made him the recipient of a UK Space Agency grant to understand how wind affects Mars, and in particular Oxia Planum – the landing site for the ExoMars programme's Rosalind Franklin rover. His previous work for the ExoMars mission included landing site selection, but his suggestion – Aram Dorsum – finished third.



Aeolian processes describe the shaping of features via wind

© El Guanche

DECIPHERING THE WINDS ON MARS

Dr Matt Balme reveals how understanding Martian breezes and storms are vital for the upcoming ExoMars mission and teases some exciting details ahead of the 'life-hunting' spacecraft's launch next year

Interviewed by Lee Cavendish

What work are you involved in for the European Space Agency and the Russian space agency Roscosmos' ExoMars mission?
Well there's a UK Space Agency grant which is to look at what we call 'aeolian processes'. Aeolian is basically [a term used to describe] anything to do with the wind, and how the wind affects the surface. We're looking at sand ripples, wind erosion and how the surface has been eroded or modified by the wind. And we're going to be doing that through my membership of the PanCam camera instrument, which is the eyes of the [Rosalind Franklin] rover.

There have also been a couple of previous UK Space Agency grants, where we were heavily involved in the new landing site selection process, so my involvement with ExoMars really goes back to 2014, where we started to propose landing sites.

Why was Oxia Planum chosen as a suitable location for landing?
It was a combination of things. Oxia Planum is interesting because it's really old, and it's in the right place, because the mission has certain constraints. For example, it can't land anywhere that has too high an elevation, because it needs a certain thickness of atmosphere for the parachutes to work. You can't land at the top of a mountain, because you'll be going too fast when you hit the surface. Oxia Planum has quite a low elevation, and it's in the right latitude range.

The ExoMars rover is going to look for life, so the landing site's got a lot of what we call 'clay minerals', which are hypothesised to be good preservers of biomarkers, and they often form due to the presence of liquid water underground. That's both the habitable environment and good preservation of anything that we might be able to detect.

And then on top of that, just to make it even better, it's also got sort of a big, ancient river channel coming into one end of the site. At the end of it it's got a fan-shaped deposit about ten kilometres [six miles] across. And that has got people thinking that it was brought there by flowing water.

Scientifically it's a really interesting place to go. But also, it's safe, it's relatively flat, it's relatively low elevation and the winds aren't too strong. It's a place where we feel that the mission will have the best chance of success.

What are the winds like on Mars, and how do they compare to those on Earth?
I guess they have similar wind speeds, possibly a bit higher in places, but the thing is that Mars' atmosphere is very low density compared to Earth's, so even if there were 100 miles [160 kilometres] an hour winds blowing, it would seem more like ten miles [16 kilometres] an hour winds.

One of the interesting things is, more recently we are seeing things like sand dunes, even quite big ones, moving on Mars. They may only be moving a metre or two a year, but maybe 20 years ago we didn't even think that was happening at all. We couldn't understand how this thin atmosphere could pick up sand particles and move them around. But there's a lot of evidence more recently that this is actually happening. People have got more into the physics of it and realised that, basically, once you start to get a bit of sand moving, it skips up into the air and is carried by the wind. And when it splashes back down into more sand it triggers a positive feedback, which keeps getting more sand going. It's still not as efficient as Earth, but there's definitely sand moving on Mars today, which is obviously what we're going to be studying in this grant.

Are these mechanisms that could lead to the global dust storms that we've seen on Mars before, and resulted in the demise of NASA's Opportunity rover?
I don't know. That's a good question. We don't really know what triggers global dust storms. The raising of dust is actually harder than the raising of sand in some ways, because dust is very small, it's kind of sticky and has a certain electrostatic effect that sticks it to the floor. We think that to trigger those sorts of storms with those amounts of dust, you're going to need sand moving in the first place, which can then help to pick up dust and move it around. It's called 'saltation triggering', as saltation is the movement of sand as it skips across the surface.

Is your aim to aid the exploration of the ExoMars rover, or to uncover a scientific understanding for when the mission gets there?

© Astrium - E Allouis

Left: The AUPE camera has been tested at locations all over the globe

Below: The movement of sand dunes on Mars is a topic of interest

© NASA/JPL-Caltech

Oxia Planum is an exciting clay-bearing site, making it a perfect candidate to accommodate the Rosalind Franklin rover

Right: The Martian poles have water ice buried beneath the surface, which some astronomers want to explore as soon as possible

© NASA

It will help the exploration, because one of the things we're doing is basically measuring how high these sort of sand patches are. On Earth we get ripples - I'm sure you have seen sand ripples if you go anywhere where there's wind and sand - but you also get dunes, which are larger accumulations.

On Mars you get ripples that can actually be almost as big as dunes. There are a lot of these things, we call them 'transverse aeolian ridges', or 'tars' for short. There are quite a few of these in parts of the Oxia Planum landing site, and when we're looking down at them with our remote sensing satellite observations, we can see how wide they are, but we can't see how high they are. One of the things that we can do with the rover is, because it's got stereo cameras, we can make nice 3D views of what's around it and we can measure the heights of things that are like these big sand ripples. They might be 30 centimetres [12 inches] high, they might be 50 centimetres [20 inches] high. What we want to know is, potentially, can we drive over them?

Part of our work will definitely be characterising where these things are in the local area using the remote sensing satellites, and then also using the views from the cameras on board the rover to work out how high steep slopes are. That will feed back into decisions made at the highest level about whether these things are going to be drive-overable or not. But of course you've got to be very, very conservative. This is a big mission, and you don't want to be too gung-ho and drive it over a sandy area and get it stuck. That would be awful. Mainly what we're doing is science - trying to understand the alien environment. But that has a role to play in helping the team work out where they can and cannot drive.

Are there any Earth analogues that you can use to test this kind of thing, or will it be largely computer model based?

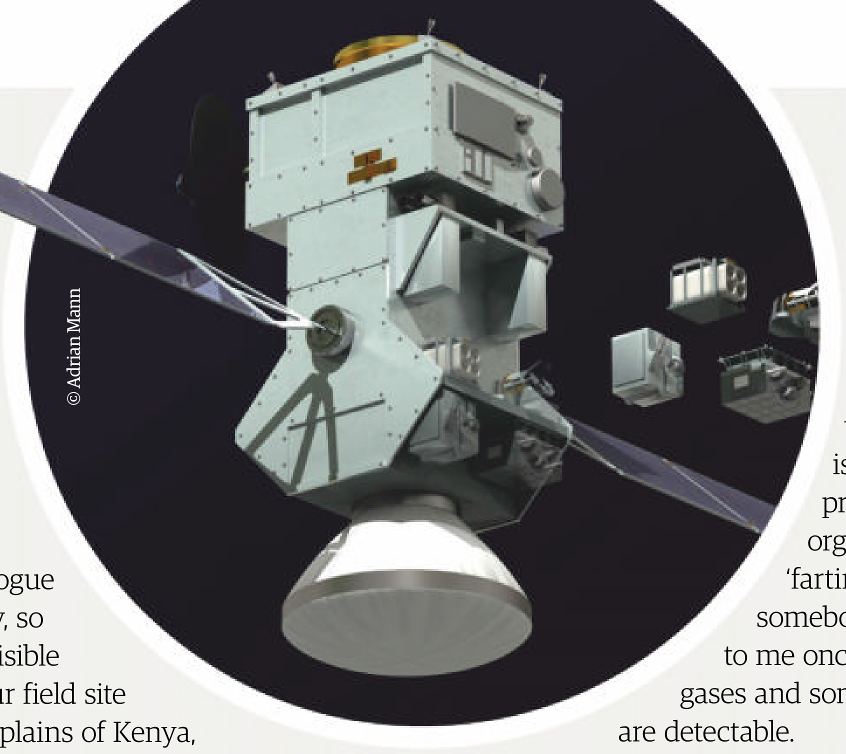
Planetary science benefits from doing a bit of everything, trying every type of approach. We are going to go into the field and we're going to take an emulator of the PanCam cameras produced in Aberystwyth [Wales]. It's called AUPE, the Aberystwyth University PanCam Emulator. Essentially it's a field-hardened version of the PanCam instrument. It mimics the PanCam instrument, but in a way that we can take it in the field and take it on planes without it getting damaged and that sort of thing.

The current plan is Iceland, but it may change. We haven't nailed down our field site yet. We're looking for somewhere that has these very large ripples - on Earth they're called 'mega ripples' - and also has wind-eroded rocks called 'ventifacts'.

Our aim is to use the AUPE PanCam emulator to see how close or how far away we need to be from different types of features to get the information that we're going to need to do the science. If we can do that on Earth, we won't have to risk the rover by trying this out on Mars.

I've also been involved in field trials where we are essentially recreating Mars in a simple way, the mission. I've been involved in three of those now: the first one was in Utah, second was in Spain, third was in Chile, in the Atacama Desert.

> "On Mars you get ripples that can actually be almost as big as dunes"



© Adrian Mann

Many missions go to the Atacama Desert to create a Mars analogue. Why is that?
It's a very good environmental analogue because it's very dry, so there's not a lot of visible life. Obviously if your field site is, I don't know, the plains of Kenya, and there are wildebeests running around the place, it's not so good. That's the main reason, because you can go there and you're not distracted by non-Mars-like environments.

But there are other reasons. There are certain types of life that exist there under low-water conditions. Certainly some of the pictures we got back we were like: 'Are we sure this isn't Mars?' It looks very much like Mars. Very much like [NASA's] Viking landing sites.

The 'methane mystery' comes up frequently when we talk about exploring Mars. What is it and how will the new ExoMars mission look to solve it?
There's the ExoMars Trace Gas Orbiter, a satellite going around Mars now. That's the first part of the ExoMars project. That has a lot of instruments that are specifically designed to look for trace gases, which are gases with a very small abundance in the atmosphere. Now previous missions, for example Mars Express, a European Space Agency mission from 2003, that found evidence, and certain ground-based telescopes found evidence of methane in the atmosphere. And the NASA Mars Science Laboratory [Curiosity] rover has also found evidence of methane. That's interesting, because it comes and goes very quickly.

However, the ExoMars Trace Gas Orbiter, as far as I know, hasn't found strong evidence for methane. Methane doesn't survive long in the atmosphere, so if it is there, then it has to be replenished by some process. And one of those processes is life. Respiration products of organisms - or 'farting bugs' as somebody described it to me once - life produces gases and some of those gases are detectable.

Now that's not the only way methane can be produced, so you have sort of two areas of controversy here. One is over which of those measurements is correct. One mission has found evidence of methane coming and going, and another instrument - from a satellite which is specifically designed to look for these sorts of things - says, 'we haven't found it, pretty much not at all'.

Then you also have the issue that even if we do find it, how do we know whether it's from life, or if it's from a geological process? Certain types of minerals can break down to produce methane and volcanoes can produce methane. It's a really interesting topic.

Over the years this will be a controversy that keeps on going, I think, until they discover that either one of the instruments has produced something incorrectly, or they eventually make another measurement that can tell us more. I think this will be a gift that keeps on giving to the scientific community.

Was there ever the thought of exploring the polar ice caps and studying the water ice?
I think it has definitely been suggested. There was a [NASA] mission called Phoenix which went to the high northern latitudes, but not up onto the polar caps. I think that was around 70 degrees north. That's where there's a lot of ice up there, and in fact it dug down and found ice buried just a few centimetres below the surface of the soil.

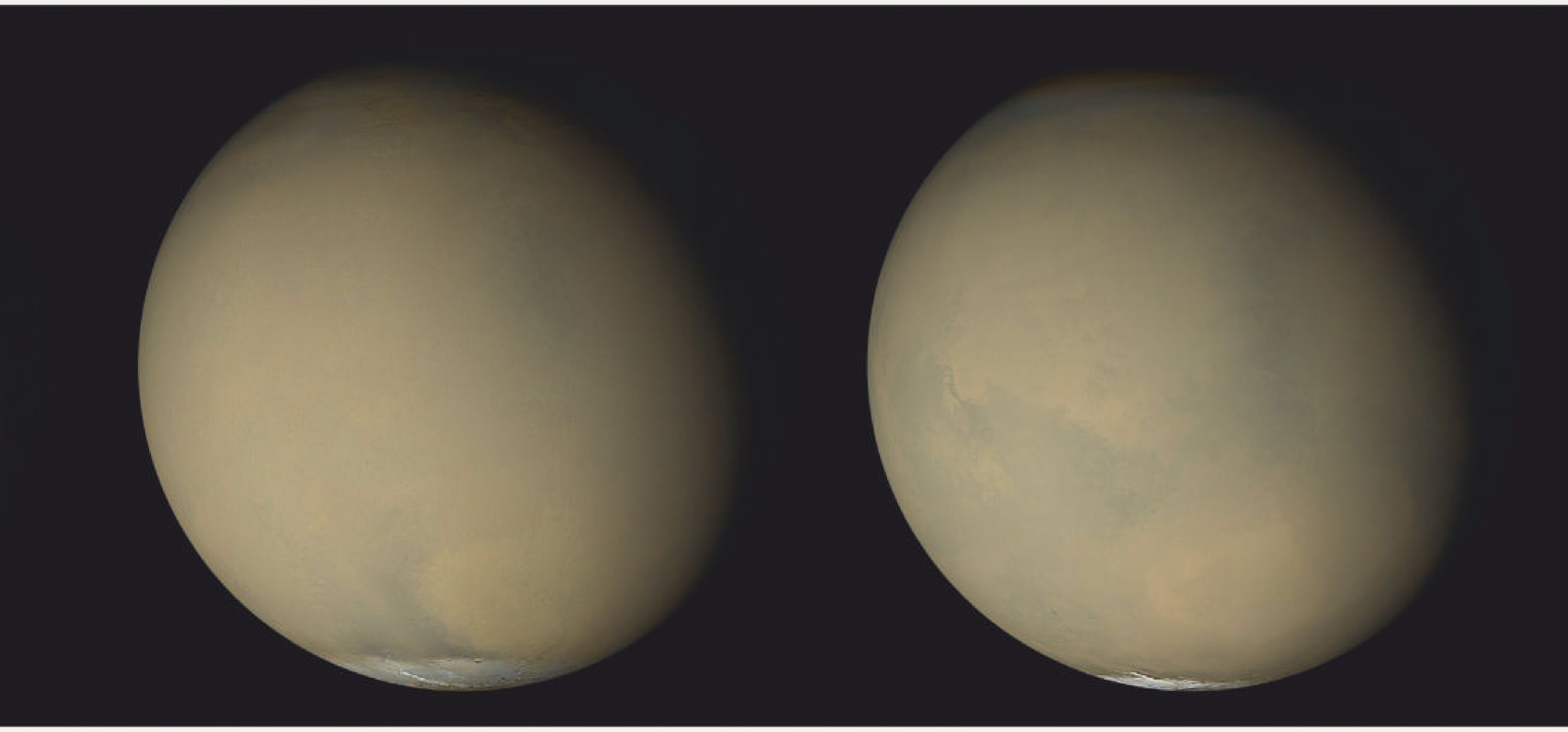
If you're going to the polar caps, that's a very challenging environment. It's very cold and you're not going to get a lot of Sun. I think people would like to go there and do some deep drilling to sample the ice caps the same way they do on Earth. This is to see if they can find a record of climate change.

At the moment it's not a priority. The priority for the next sort of ten years or so is to explore the ancient parts of Mars, where we think evidence for past life might be preserved if it were there, and bring back a sample.

A Mars sample-return mission is going to be the focus of the 2020s. The polar caps are really interesting, but I think they will have to wait before somebody plans a feasible mission in a feasible time scale with a feasible budget.

So that's the next aim of the ExoMars mission after the rover? A sample-return mission?
Yes, this is going to be a global event. We're going to be working with the Americans and the European Space Agency. I don't think it's nailed down exactly what we're going to do, but the NASA 2020 rover will be collecting samples, putting them in little storage containers and they will be collected by what's called the Sample Fetch Rover. The Sample Fetch Rover will take it back to an ascent vehicle, and that will rise from the Martian surface with the samples, meet another vehicle that is in orbit and transfer the samples to that vehicle, which will then make its way back to Earth.

It is pretty complicated, so you can understand there's a huge engineering challenge to do all this stuff. One of the things that's happening now is the design of the Sample Fetch Rover and design of the system for picking up these 'cached' samples. The caching system is already designed. That's on board NASA's Mars 2020. Next year that'll be launching around the same time as ExoMars, and so in 2021, there should be - fingers crossed - two new rovers on the surface of Mars.



© NASA/JPL-Caltech/MSSS

Above: The ExoMars Trace Gas Orbiter arrived at Mars in October 2016

Left: Mars has been known to experience dust storms that envelop most of the planet

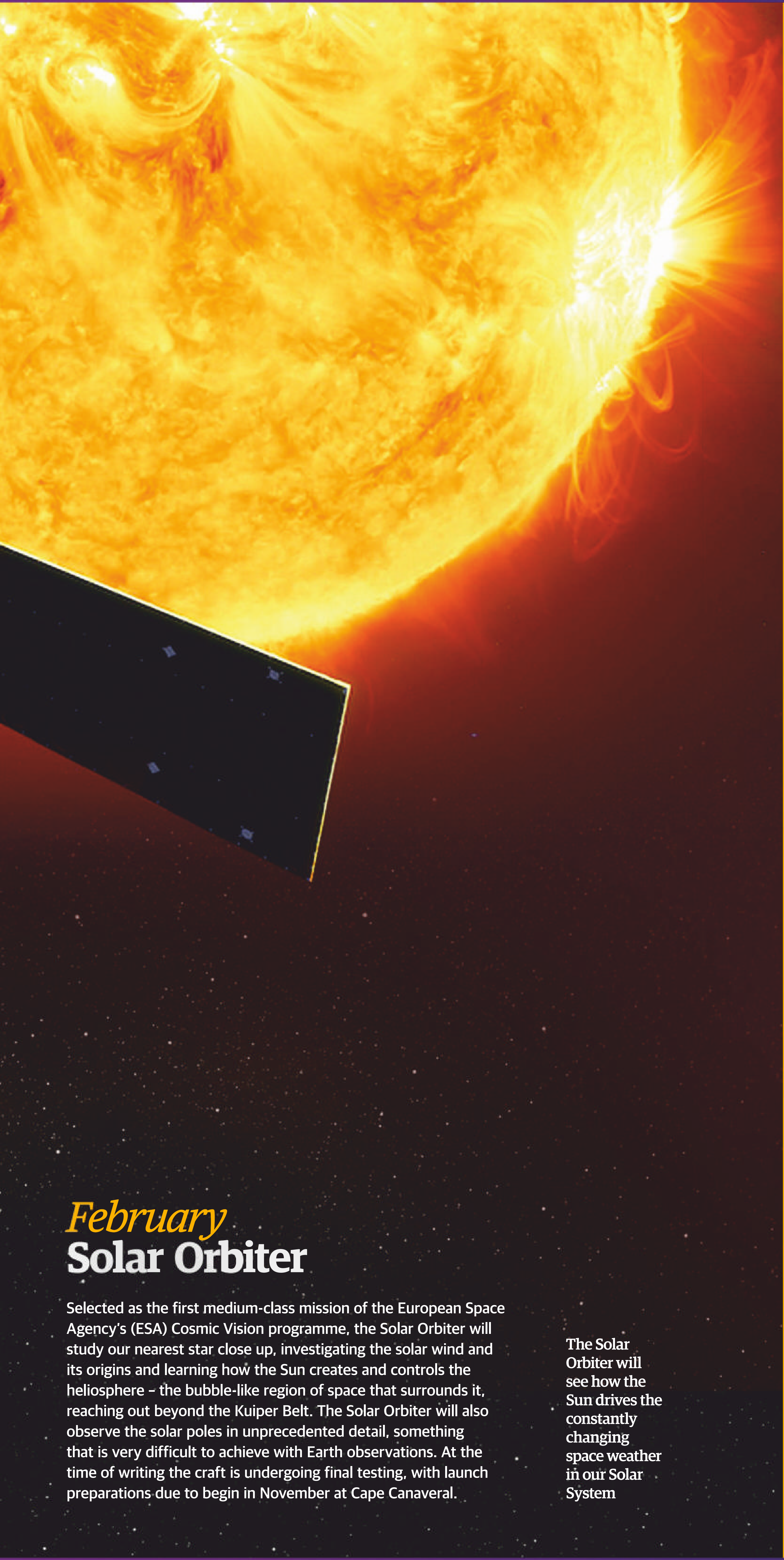
© ESA

2020 SPACE EVENTS

The unmissable mission launches and astronomy events to watch next year

Reported by Nikole Robinson

In the last decade we've seen incredible developments in space technology and exploration, and the next ten years will see more great achievements, like humanity's return to the Moon and the launch of new spacecraft to explore more of the Solar System. With more countries and private enterprises now reaching for the stars, next year is once again full of exciting mission launches, as well as astronomical events worth viewing with your trusty telescope, binoculars or even with the naked eye. Whether you're waiting for your next planetary opposition or rocket launch, there's something for every fan of astronomy and space exploration to get excited about.



February
Solar Orbiter

Selected as the first medium-class mission of the European Space Agency's (ESA) Cosmic Vision programme, the Solar Orbiter will study our nearest star close up, investigating the solar wind and its origins and learning how the Sun creates and controls the heliosphere – the bubble-like region of space that surrounds it, reaching out beyond the Kuiper Belt. The Solar Orbiter will also observe the solar poles in unprecedented detail, something that is very difficult to achieve with Earth observations. At the time of writing the craft is undergoing final testing, with launch preparations due to begin in November at Cape Canaveral.

The Solar Orbiter will see how the Sun drives the constantly changing space weather in our Solar System

ESA astronaut Thomas Pesquet snapped this supermoon shot from the ISS

© ESA

9 March, 8 April, 7 May
Three supermoons

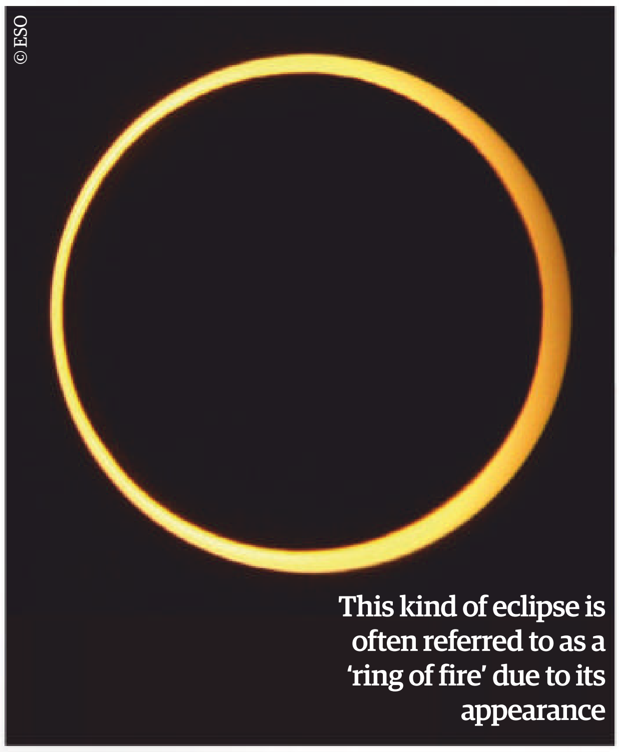
A supermoon occurs when the full Moon coincides with our satellite's perigee – its closet point of approach during its elliptical path around the Earth – with the Moon needing to be within 360,000 kilometres (224,000 miles) of Earth to be considered a supermoon. The Moon will appear bigger and around 16 per cent brighter than usual. The Moon's apparent larger size will look its most extreme at moonrise or moonset, when the Moon is closest to the horizon. If you enjoy lunar viewing, these three months will provide some excellent views and astrophotography opportunities.

Victor Glover (left) and Michael Hopkins (right) stand in front of a mockup of Dragon 2

© SpaceX

May
First crewed flight of SpaceX's Dragon 2 (USCV-1)

Launching on a Falcon 9 from the Kennedy Space Center, this will be the third orbital flight of the reusable Dragon 2 spacecraft, but the first to carry human passengers, transporting commander Michael Hopkins, pilot Victor Glover and mission specialist Soichi Noguchi to the International Space Station (ISS). Dragon 2 will remain docked to the ISS for six months after delivering the astronauts to their new home. The Dragon 2 craft is capable of carrying up to seven astronauts, and will continue to ferry crews to the ISS as part of the Commercial Crew program.



© ESO

This kind of eclipse is often referred to as a 'ring of fire' due to its appearance

21 June

Annular solar eclipse

It's only coincidental that the Sun and Moon are an almost-identical size as viewed from Earth, and it is this that makes a solar eclipse possible. However, because the Moon has an elliptical orbit, sometimes when it passes in front of the Sun it is unable to cover the entire face of our star. This is called an annular solar eclipse, and does not result in totality. The path of the eclipse will begin in central Africa and travel through Saudi Arabia, northern India and southern China before ending in the Pacific Ocean. A partial eclipse will be visible throughout most of eastern Africa, the Middle East and southern Asia.

© NASA/JPL-Caltech

17 July to 5 August

Mars 2020

NASA's next rover will launch from Cape Canaveral on its way to the Jezero crater on Mars – a crater once thought to have been flooded with water. The rover's design is based on the successful Curiosity rover which has been exploring Mars since 2012. The mission will look to confirm if Mars was habitable in its ancient past and search for biosignatures of past microbial life. The rover will also collect samples of surface soil and rock for a proposed future mission to bring back to Earth for study, as well as preparing NASA for future human exploration of the Red Planet by attempting an experiment to produce oxygen from the Martian atmosphere.

July

OSIRIS-REx takes a sample

NASA's Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer, or OSIRIS-REx, made its journey to carbonaceous asteroid 101955 Bennu, arriving in December 2018. Since then it has been studying the near-Earth asteroid while trying to locate an area from which to collect a sample for return to Earth. During this collection OSIRIS-REx will slowly descend towards the surface until its TAGSAM instrument makes contact. A burst of nitrogen will then be released which will send particles into the sampler at the end of the robotic arm.

A concept image of China's Mars rover and lander released in 2016

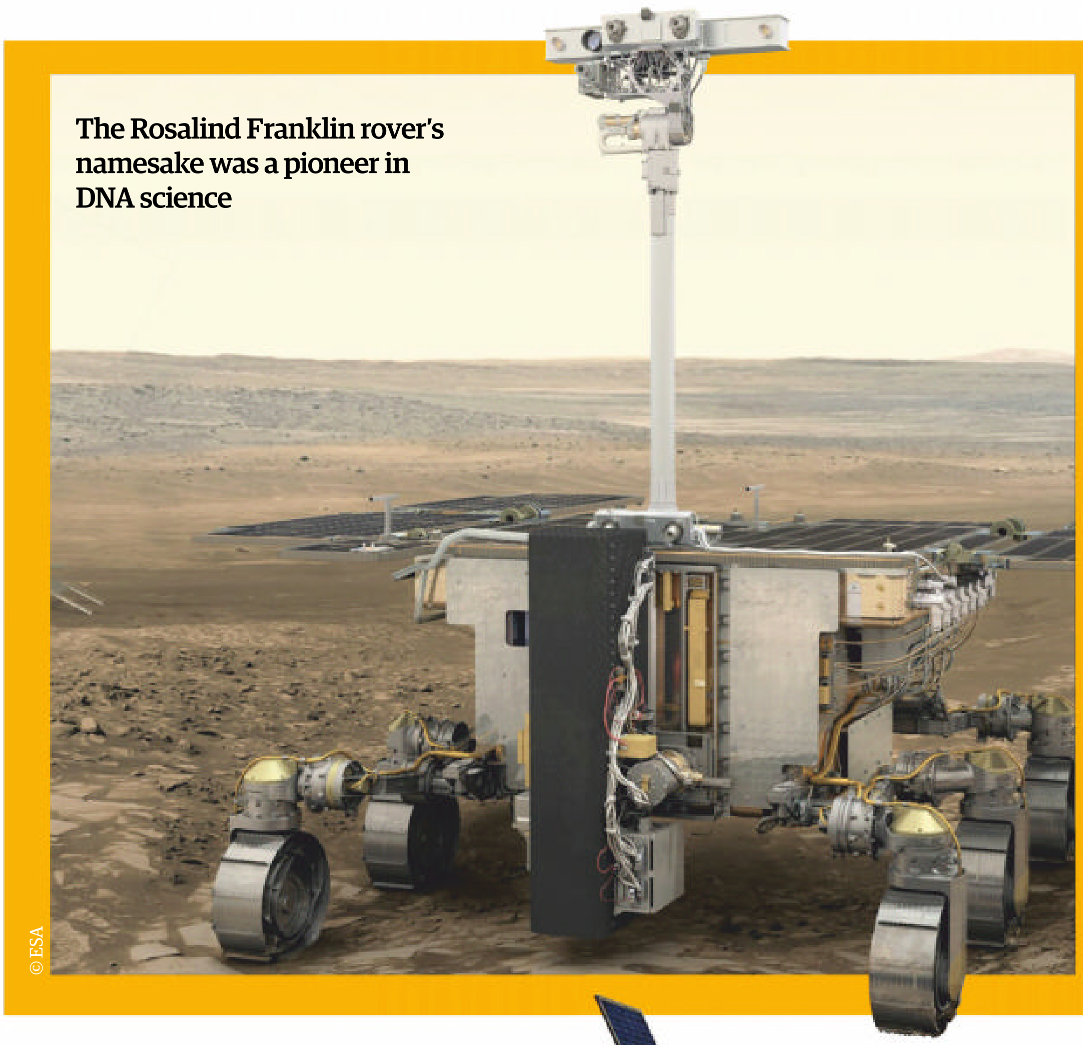
© Chinese Academy of Sciences

23 July to 5 August

HX-1

After the unfortunate crash of the China National Space Administration's (CNSA) first Mars exploration probe, Yinghuo-1, the country began to develop a Mars orbiter and rover combination, now known as the Mars Global Remote Sensing Orbiter and Small Rover, or HX-1. Planned to launch using China's heavy-lift launch system, the Long March 5, the orbiter and rover will work to produce maps of the Martian surface, studying its topography, material composition, atmosphere and other properties. Like most recent missions sent to our neighbouring planet, it will also look for traces of life. The mission will also act as a demonstration of technology for a future Chinese sample-return mission.

One orbit of the asteroid Bennu takes OSIRIS-REx around 62 hours



The Rosalind Franklin rover's namesake was a pioneer in DNA science

© ESA

25 July

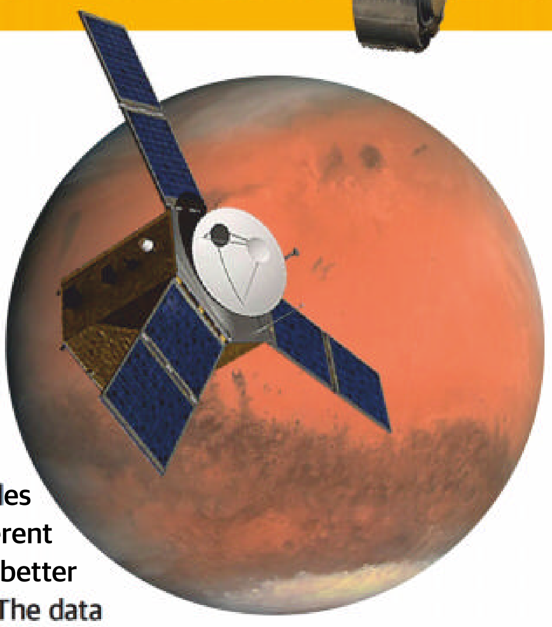
ExoMars Rosalind Franklin rover

A collaborative effort between the ESA and Russia's Roscosmos, the ExoMars programme has already seen the launch of the Trace Gas Orbiter, which has been orbiting Mars since 2016. As well as performing its own science missions, the orbiter will also act as a relay for the Rosalind Franklin rover, due to launch next year. The search for life is at the core of the ExoMars programme. The rover's landing site of Oxia Planum was chosen with this in mind, as it is one of the largest exposures of clay-bearing rocks. The rover has a drill that can penetrate two metres (6.5 feet) into the planet's surface to extract samples for analysis. Although the rover will not analyse atmospheric samples, the Kazachok lander that will deploy it is equipped with a meteorological station.

July

Hope Mars

Also called the Emirates Mars Mission, upon launch it will become the first mission to Mars by a Muslim-majority country. It goals are aimed at expanding knowledge of the Martian atmosphere, studying the climate and its seasonal cycles as well as comparing the weather in different geographical areas of Mars and trying to better understand events such as dust storms. The data will allow astronomers to study the climate changes seen in Mars and the loss of the planet's hydrogen and oxygen into space.



Hope's arrival at Mars will coincide with the 50th anniversary of the formation of the UAE

10 January, 5 June, 5 July, 30 November

Penumbral lunar eclipses

The Moon appears to glow due to reflected light from the Sun, and when Earth moves between the Sun and Moon, it blocks some of this reflected light. A penumbral eclipse occurs when the three aren't perfectly aligned, with Earth only blocking part of the light with its outer shadow, the penumbra. Depending on how the Moon sits in this shadow, its colour can change. Some penumbral eclipses look no different to the normal full Moon, while others are much more striking, taking on a darker, yellowed or ruddy appearance. Although four occur in 2020, they will not be visible from all parts of the world.

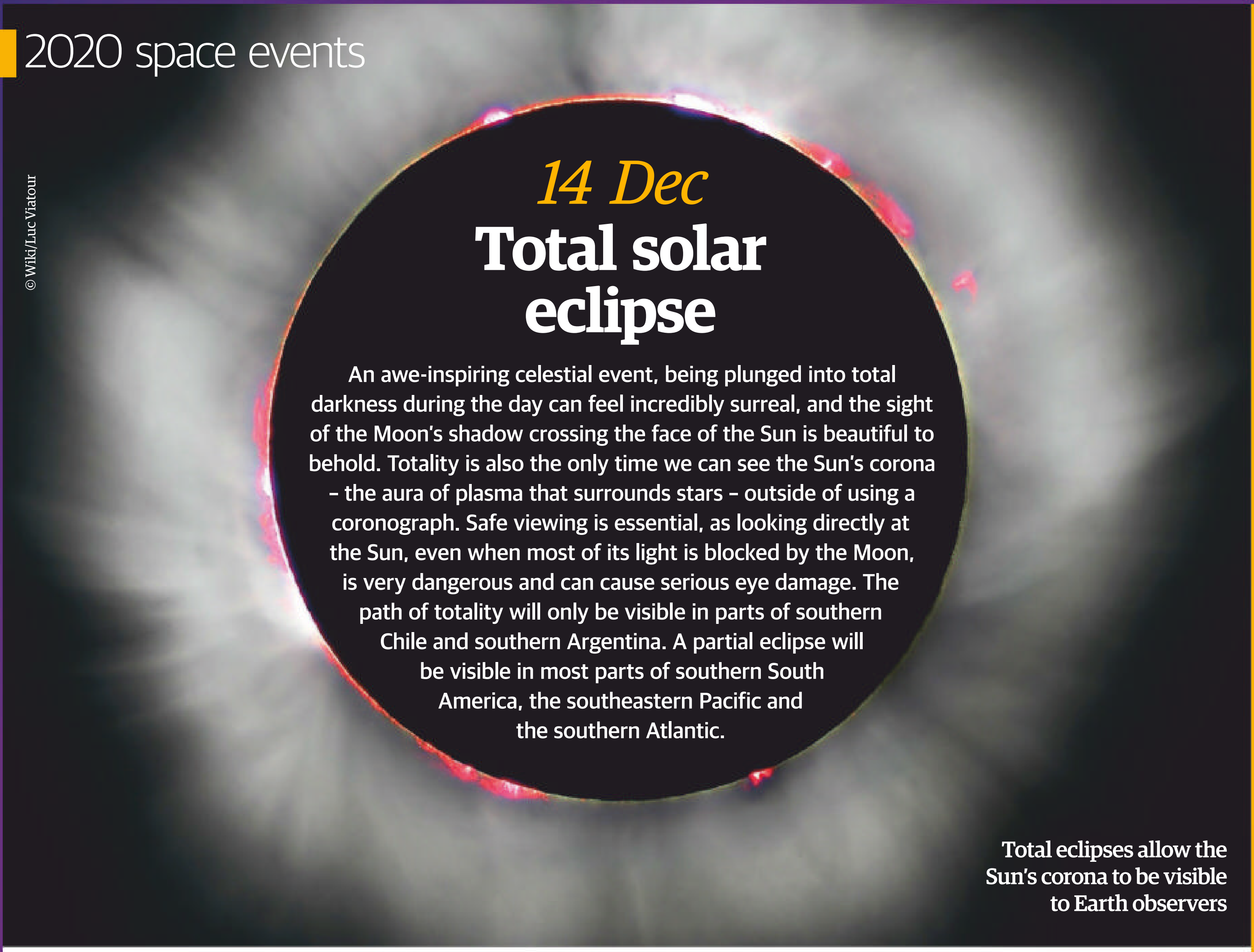
Penumbral eclipses aren't as red as a full lunar eclipse, but can appear yellowish or ruddy

© NASA

November

Artemis 1

NASA and the ESA are getting ready for a manned mission to the Moon with the Artemis 1 mission, which will test both the Orion Multi-Purpose Crew Vehicle and the Space Launch System (SLS). The Block 1 version of the super heavy-lift rocket will launch the uncrewed Orion towards the Moon no earlier than November 2020, though it may be later depending on how testing goes before next year. Orion will then spend around three weeks in space, including six days of retrograde orbit around our natural satellite. If all goes well a crewed follow-up – Artemis 2 – is planned between 2022 and 2023.



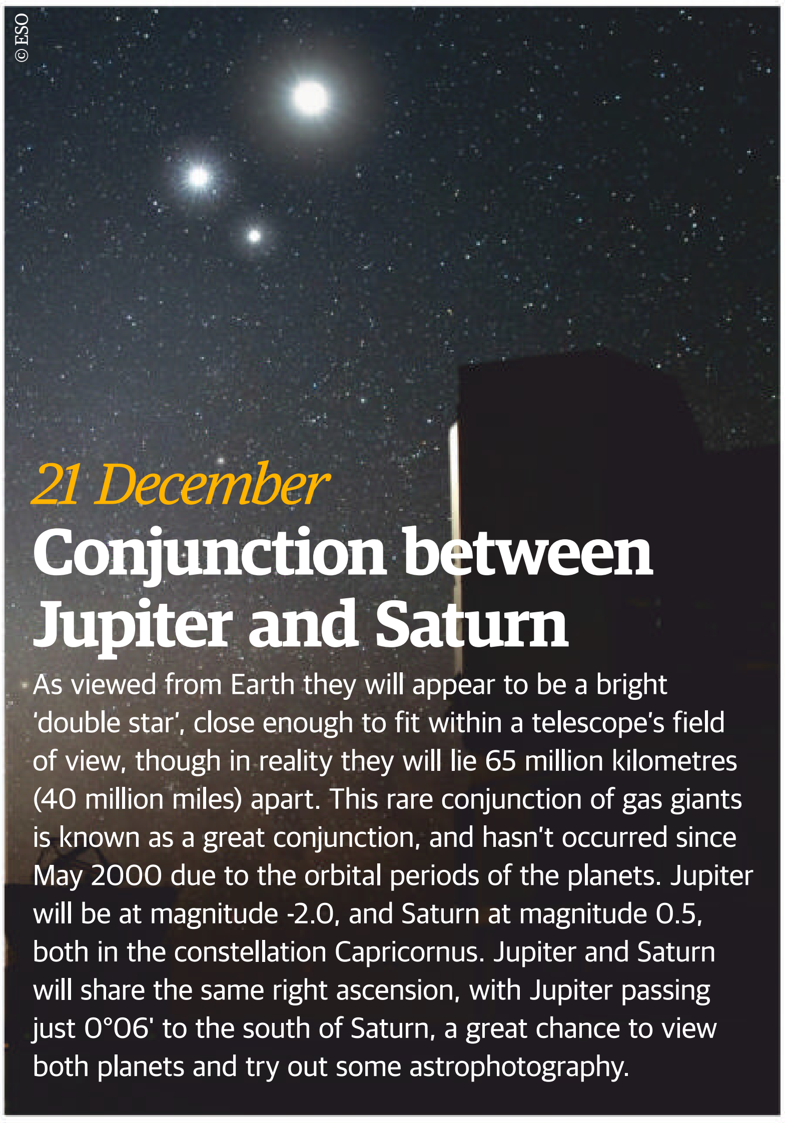
© Wiki/Luc Viatour

14 Dec

Total solar eclipse

An awe-inspiring celestial event, being plunged into total darkness during the day can feel incredibly surreal, and the sight of the Moon's shadow crossing the face of the Sun is beautiful to behold. Totality is also the only time we can see the Sun's corona – the aura of plasma that surrounds stars – outside of using a coronograph. Safe viewing is essential, as looking directly at the Sun, even when most of its light is blocked by the Moon, is very dangerous and can cause serious eye damage. The path of totality will only be visible in parts of southern Chile and southern Argentina. A partial eclipse will be visible in most parts of southern South America, the southeastern Pacific and the southern Atlantic.

Total eclipses allow the Sun's corona to be visible to Earth observers



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21 December

Conjunction between Jupiter and Saturn

As viewed from Earth they will appear to be a bright 'double star', close enough to fit within a telescope's field of view, though in reality they will lie 65 million kilometres (40 million miles) apart. This rare conjunction of gas giants is known as a great conjunction, and hasn't occurred since May 2000 due to the orbital periods of the planets. Jupiter will be at magnitude -2.0, and Saturn at magnitude 0.5, both in the constellation Capricornus. Jupiter and Saturn will share the same right ascension, with Jupiter passing just 0°06' to the south of Saturn, a great chance to view both planets and try out some astrophotography.

December

Hayabusa2 sample return arrives at Earth

The Japan Aerospace Exploration Agency's (JAXA) second asteroid-sampling mission arrived at its target 162173 Ryugu last year. The craft studied the near-Earth object in detail, deploying rovers onto its surface and examining it for the perfect site to take a sample from. The craft took two samples, the first on 21 February and the second on 11 July 2019, storing them inside separate containers for return to Earth. When Hayabua2 flies past Earth in December 2020, it will release the sample-return capsule. If all goes well the sample-return capsule will land safely at the Woomera Test Range in Australia.

© Mj-bird

Planets at opposition

When a planet reaches opposition it is directly opposite the Sun in the sky relative to Earth. Planets will usually appear larger and brighter at this time because their orbits are closer to Earth, and will be visible for most – if not all – of the night, making it a great time for observation.

Jupiter
14 July
Sagittarius

Saturn
20 July
Sagittarius

Neptune
10 September
Aquarius

Mars
13 October
Pisces

Uranus
31 October
Aries

Meteor showers

These fantastic shows of 'falling stars' occur all throughout the year. It is worth paying attention to the phase of the Moon as well as the peak of the shower, as visibility of the fainter meteors can be marred the more full and bright the Moon is.

Quadrantids

Dates	12 December to 12 January
Peak	4 January
Max per hour	120
Constellation	Boötes

Lyrids

Dates	16 to 25 April
Peak	22 April
Max per hour	18
Constellation	Lyra

Eta Aquarids

Dates	19 April to 28 May
Peak	5 May
Max per hour	40
Constellation	Aquarius

Arietids

Dates	14 April to 24 June
Peak	7 June
Max per hour	50
Constellation	Aries

Delta Aquarids

Dates	12 July to 23 August
Peak	30 July
Max per hour	25
Constellation	Aquarius

Perseids

Dates	17 July to 24 August
Peak	13 August
Max per hour	150
Constellation	Perseus

Draconids

Dates	6 to 10 October
Peak	8 October
Max per hour	10
Constellation	Draco

Orionids

Dates	2 October to 7 November
Peak	21 October
Max per hour	15
Constellation	Orion

Taurids

Dates	20 October to 10 December
Peak	12 November
Max per hour	5
Constellation	Taurus

Leonids

Dates	6 to 30 November
Peak	17 November
Max per hour	15
Constellation	Leo

Geminids

Dates	4 to 17 December
Peak	14 December
Max per hour	120
Constellation	Gemini

Ursids

Dates	17 to 26 December
Peak	22 December
Max per hour	10
Constellation	Ursa Minor

APOLLO 11
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SPECIAL EDITION SPACE PENS

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Matte Black Bullet Space Pen
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Planet profile

Mercury

The minute world is arguably the least explored of the four terrestrial planets

Mercury is a planet that has sculpted not only our scientific understanding over generations, but also our culture. Mercury has been mentioned in text dating as far back as the 2nd millennium BCE by the Sumerians, and the ancient namesake of the planet is the Roman messenger god, Mercury.

Mercury is the smallest of all the planets in the Solar System and the closest planet to the Sun, but there is so much more to it. Mercury is so tiny compared to the other planets that you can actually fit around 23,500 Mercurys into Jupiter, and it is roughly 1,400 kilometres (870 miles) larger in diameter than the Moon. The small planet also orbits the Sun with less than half the distance between the Sun and the Earth, resulting in it being 'tidally locked'.

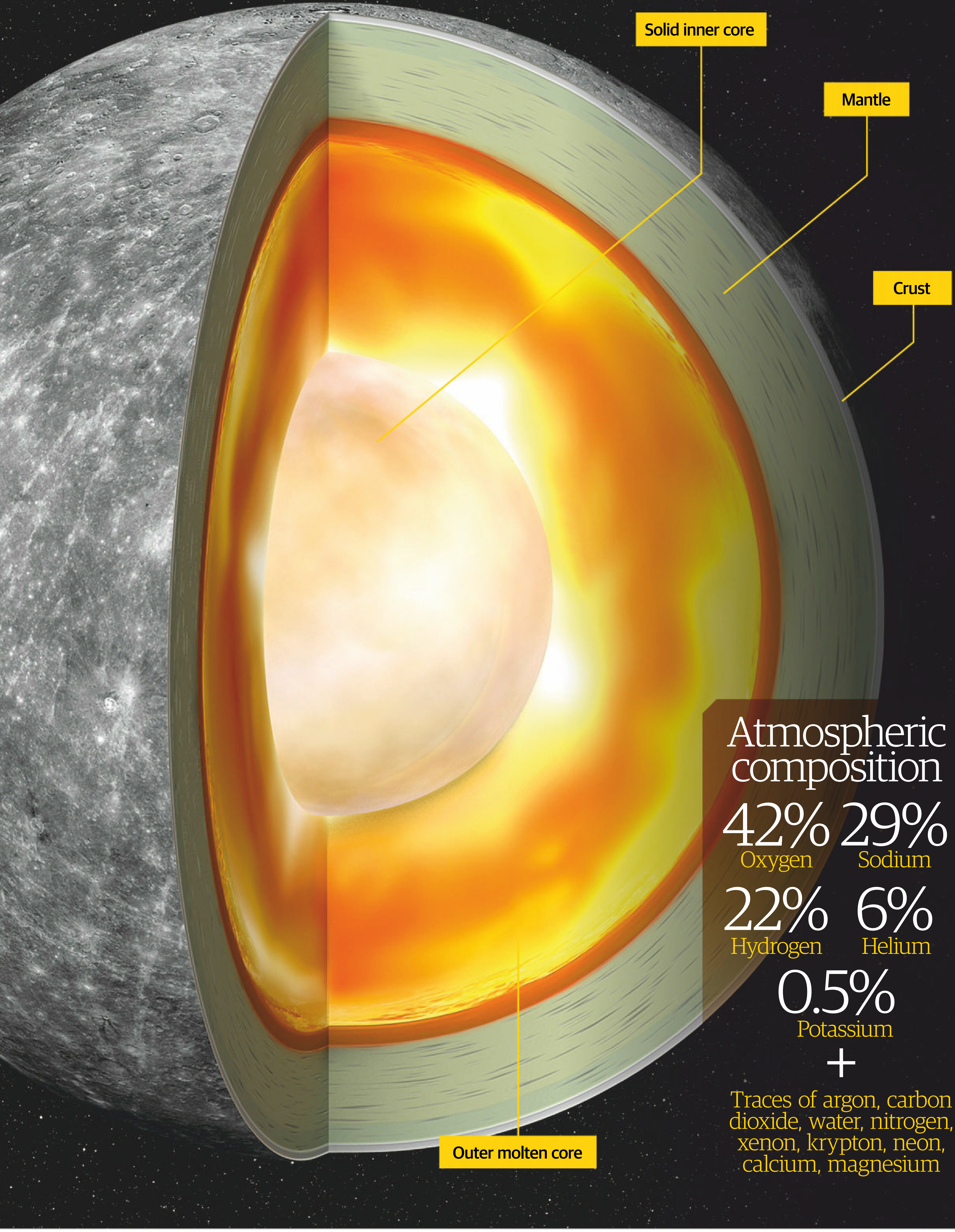
Tidal locking occurs when an object is so close to its host object that the gravity is overwhelmingly powerful, and instead of continuously spinning on its axis, like Earth does, the object has one side facing towards the host object at all times. In this case Mercury is tidally locked to the Sun, and for every two revolutions around the Sun, Mercury rotates on its axis three times. Each orbit takes 88 Earth days, making a year on Mercury roughly a quarter of an Earth year.

Because Mercury is so close to the Sun, the surface temperatures can be scorching, reaching highs of 450 degrees Celsius (840 degrees Fahrenheit). Enduring this bombardment of radiation from the Sun, the planet also struggles to keep hold of its atmosphere, meaning that no heat is trapped. This means the night side of the planet – facing away from the Sun – can have temperatures as low as -180 degrees Celsius (-290 degrees Fahrenheit).

While Mercury is a similar size to the Moon, it is also similar in appearance. It is a heavily cratered, rocky body with some of the largest craters in the Solar System. One crater studied by previous exploration missions is a great example. The Caloris basin, which is roughly 1,550-kilometres (960-miles) wide, is about the size of Texas, and was formed when an asteroid about 100 kilometres (60 miles) across hit Mercury's surface 4 billion years ago, impacting the planet with energy equivalent to a trillion one-megaton bombs.

If you scratch beneath the surface, the true weirdness of Mercury starts to become apparent. Under the ultra-thin cratered crust is an extremely dense planet, with somewhere between 70 and 85 per cent of the planet being an enormous iron core. Astronomers have spent years constraining whether it is solid, molten or both, and they seem to agree it has a solid iron core with an outer molten core. Astronomers believe that a molten core could explain Mercury's very weak magnetic field. However, after the results were brought back and analysed from NASA's Mariner 10 and MESSENGER space probes, astronomers now believe that Mercury is the exposed core of a much larger planet, with its outer layers lost to a powerful collision billions of years ago.

> "Astronomers now believe that Mercury is the exposed core of a much larger planet, with its outer layers lost to a powerful collision"



Atmospheric composition

42% Oxygen

29% Sodium

22% Hydrogen

6% Helium

0.5% Potassium

+

Traces of argon, carbon dioxide, water, nitrogen, xenon, krypton, neon, calcium, magnesium

© NASA

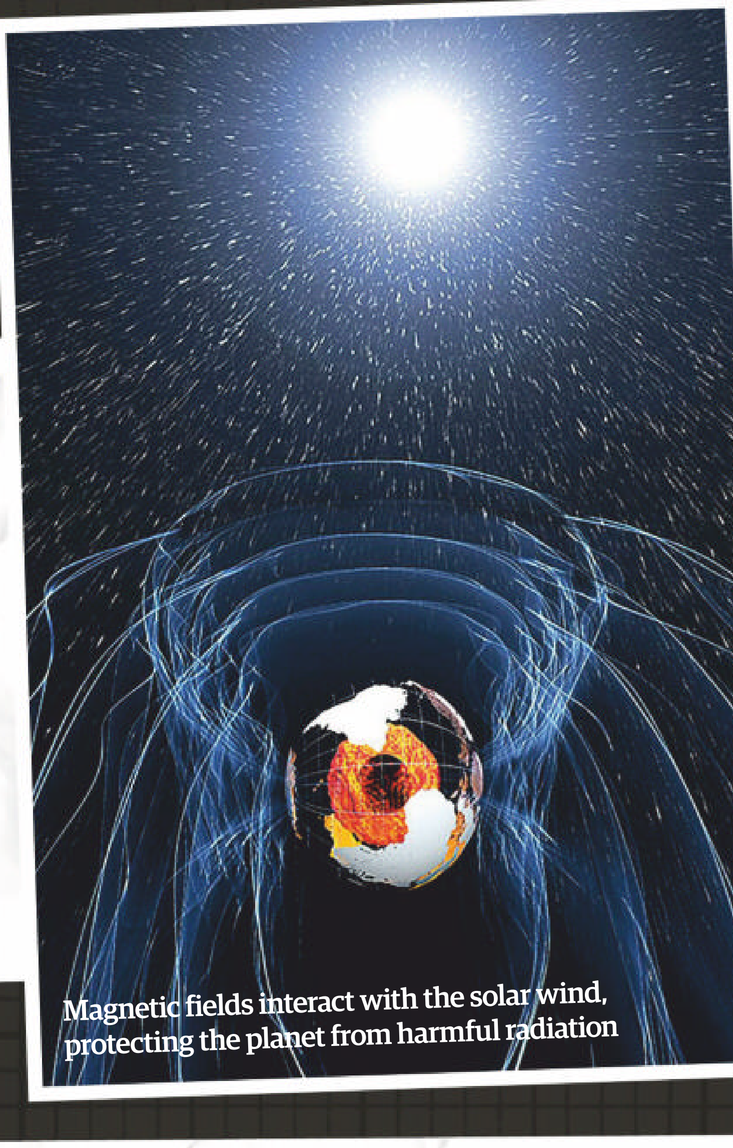
What's been happening at Mercury?

Mercury's magnetic irregularities

A magnetic field is the result of the motion of an internal molten core, and that is certainly the case on Earth. Earth's magnetic poles have also been known to shift in location from time to time, but now astronomers have suggested that Mercury's ancient magnetic poles have been doing the same thing.

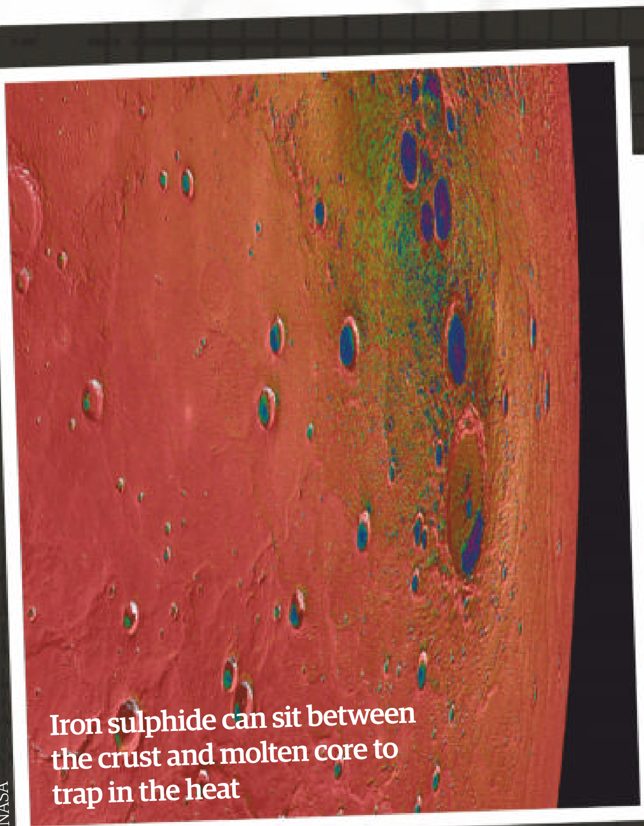
Mercury's ancient magnetic poles, known as paleopoles, appear to have shifted throughout time, and this could present clues in the investigation of Mercury's interior. By understanding the magnetic field, astronomers could pinpoint the nature of the planet's molten core. "There are several evolution models of the planet, but no one has used the crustal magnetic field to obtain the planet's evolution," says Joana S. Oliveira, an astrophysicist at the European Space Agency's European Space Research and Technology Centre in Noordwijk, the Netherlands.

These results came from NASA's MESSENGER data collected on ancient craters that had irregular magnetic signatures. Not only would a further analysis help us understand the nature of Mercury's interior, it could have implications for understanding how the planet evolved, and even how Earth's magnetic field evolved.



Magnetic fields interact with the solar wind, protecting the planet from harmful radiation

© ESA/ATG medialab



Iron sulphide can sit between the crust and molten core to trap in the heat

© NASA

An insulating blanket of iron sulphide

Once again Mercury's magnetic field is the centre of astronomers' research. However, instead of trying to understand the nature of it, astronomers are trying to understand how it is kept in place. Astronomers have seen with Mars how a planet much smaller than Earth can solidify and lose its molten core, and consequently lose its magnetic field, but Mercury still appears to have one.

This recent research suggests that a layer of iron sulphide could be insulating the core, maintaining its molten state. "Based on lab experiments, we got some data to explain how actually you can generate such a low magnetic field and sustain it for such a long time," says mineral physicist Geeth Manthilake of Clermont Auvergne University in Clermont-Ferrand, France.

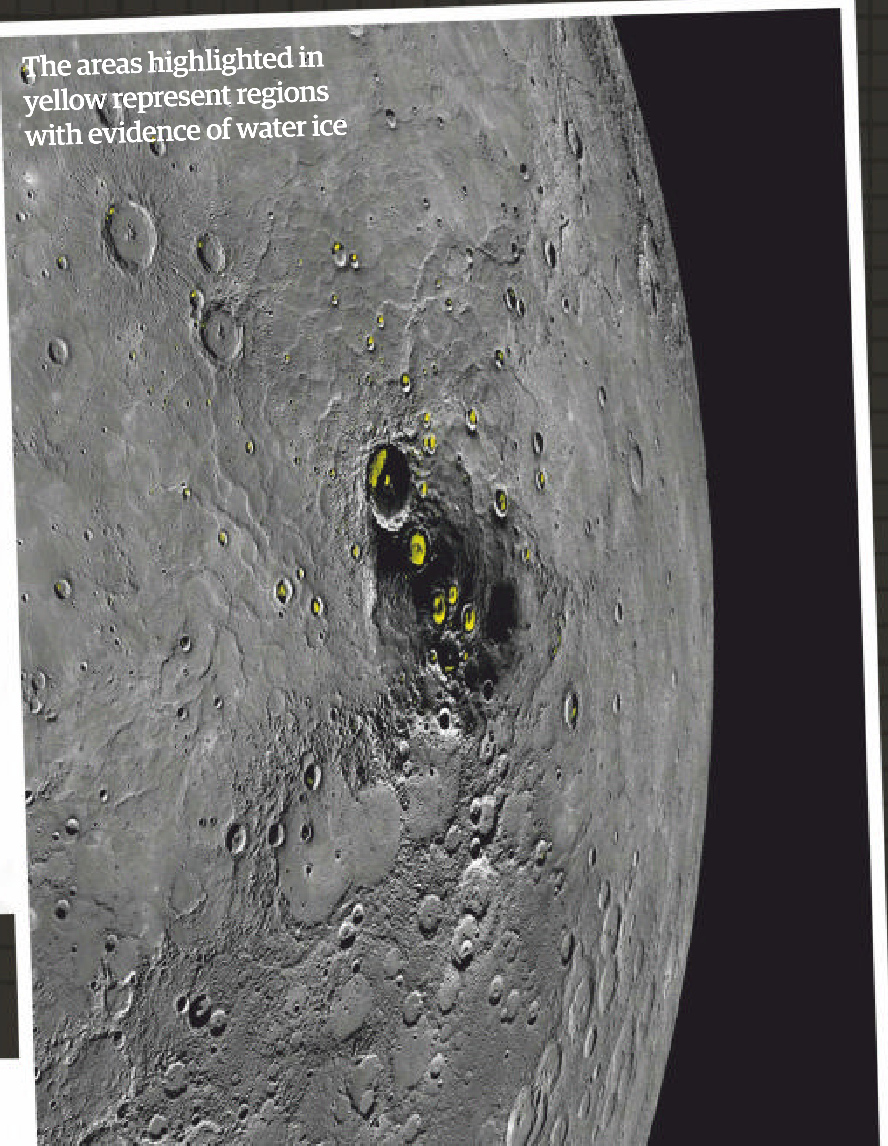
These experiments predict that Mercury has a solid inner core, with a molten outer core of iron, sulphur and silicon. Much like water and oil, these elements can't mix, so the iron and sulphur compounds were expelled towards the outer regions of the planet and created the insulating layer.

"A layer of iron sulphide could be insulating the core, maintaining its molten state"

Searching for water ice on Mercury

The search for water elsewhere in the Solar System has become more of a hunt among astronomers as engineers and scientists alike keep a keen eye out for its cosmic signature and prepare for a mission to the Moon's poles. Mercury is another body that astronomers suspect is hiding the valuable comodity at its poles, with NASA's MESSENGER space probe revealing the signatures of thick deposits of water ice hidden in craters at the planet's poles. In these craters, sunlight doesn't reach the depths within, and therefore they're sheltered from the radiation that could cause water ice to dissipate. Astronomers believe these craters could hold answers about where water is dispersed throughout the Solar System and even the origins of life itself.

Astronomers have also been comparing Mercury and the Moon to try and understand what the water ice in these craters may look like. This involved looking at about 14,000 craters on the two bodies, over 2,000 of which are on Mercury. They have come to the conclusion that on the Solar System's smallest planet, craters that harbour ice have shallower sides than those that don't.



The areas highlighted in yellow represent regions with evidence of water ice

© NASA

Exploring the past and future of the swift planet

Visiting Mercury is a dangerous and difficult task. Some may think that this is because it's a relatively small planet and therefore more difficult to navigate to, but that is far from the case. The voyage to Mercury is difficult because of the humongous ball of searing plasma, the Sun, and its pesky gravity. Navigating a spacecraft to Mercury requires propulsion that will get it to Mercury and also counteract the gravity of the Sun so the craft doesn't go falling into the surface and burn up. This is why only two spacecraft have ever visited the small terrestrial planet.

NASA has been the operator of both of these missions, the first being Mariner 10 in 1974, which conducted a series of flybys and gathered close-up images. However, the mission that brought the most consistent and fascinating results is the MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) spacecraft, which is the first and only spacecraft so far to orbit the planet. MESSENGER's most important results included how volatile-rich the planet was – volatiles being chemical compounds with low boiling points – which has important implications for the planet's formation. Also there were its ice deposits at the poles, its weird magnetic field offset and its irregular depressions called 'hollows'.

The next mission to Mercury is the exciting BepiColombo, a joint endeavour by the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA). This mission will arrive at Mercury in 2025, where it will separate into two orbiters and use its impressive instrumental suite to investigate the planet from all angles.

The Mercury Planetary Orbiter (MPO) was built and will be operated by the ESA, and the Mercury Magnetospheric Orbiter (Mio) was built and will be operated by JAXA. This unique mission will have its two orbiters working simultaneously as scientists get up-close observations of the surface and far-away observations of the magnetic field.

MESSENGER spent the best of four fruitful years at Mercury

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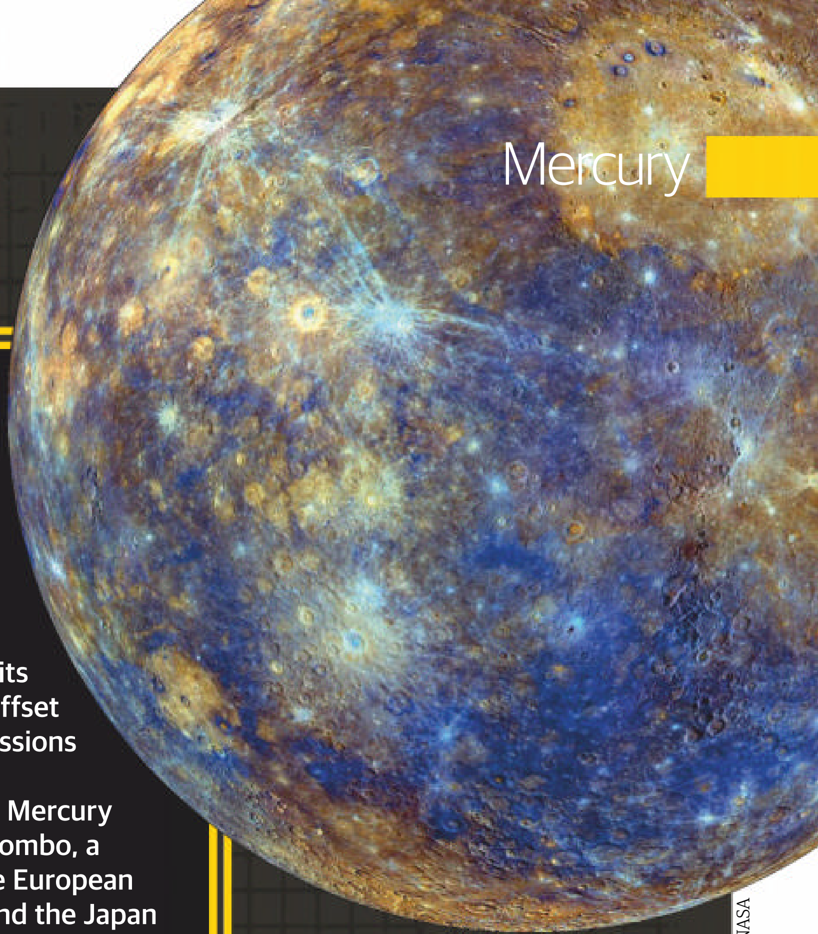


© NASA

Using MESSENGER's colour base map imaging, Mercury is shown in a colourful contrast

BepiColombo's seven-year journey to Mercury

Date: 20 October 2018
Activity: Launch from Earth

Date: 13 April 2020
Activity: Earth flyby

Date: 16 October 2020
Activity: First Venus flyby

Date: 11 August 2021
Activity: Second Venus flyby

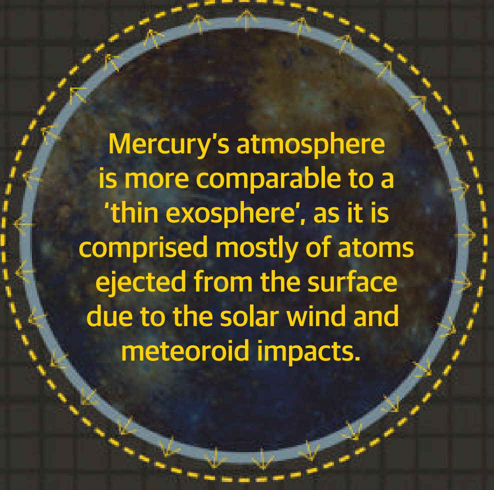
Date: 2 October 2021
Activity: First Mercury flyby

Date: 9 January 2025
Activity: Sixth Mercury flyby

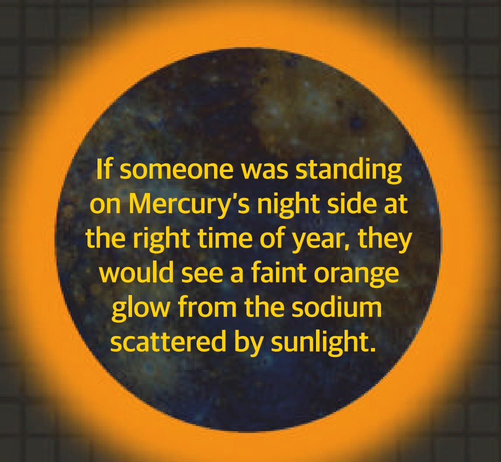
Date: 5 December 2025
Activity: Orbital insertion around Mercury

Mercury facts

Mercury has no moons, making it one of two planets in the Solar System – along with Venus – to not have its own moon.



Mercury's atmosphere is more comparable to a 'thin exosphere', as it is comprised mostly of atoms ejected from the surface due to the solar wind and meteoroid impacts.

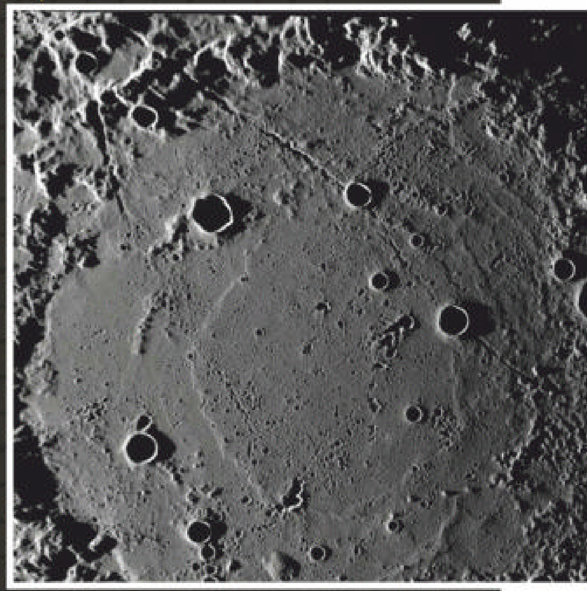


If someone was standing on Mercury's night side at the right time of year, they would see a faint orange glow from the sodium scattered by sunlight.

One day on Mercury lasts 59 Earth days – an incredibly long time in comparison – while a year on Mercury lasts just 88 Earth days.

NASA's MESSENGER mission stayed in orbit around Mercury from March 2011 to April 2015 before crashing into the surface of the planet.

Astronomers believe there was active volcanism on Mercury at some point, as there are areas that appear to have been flooded with lava.



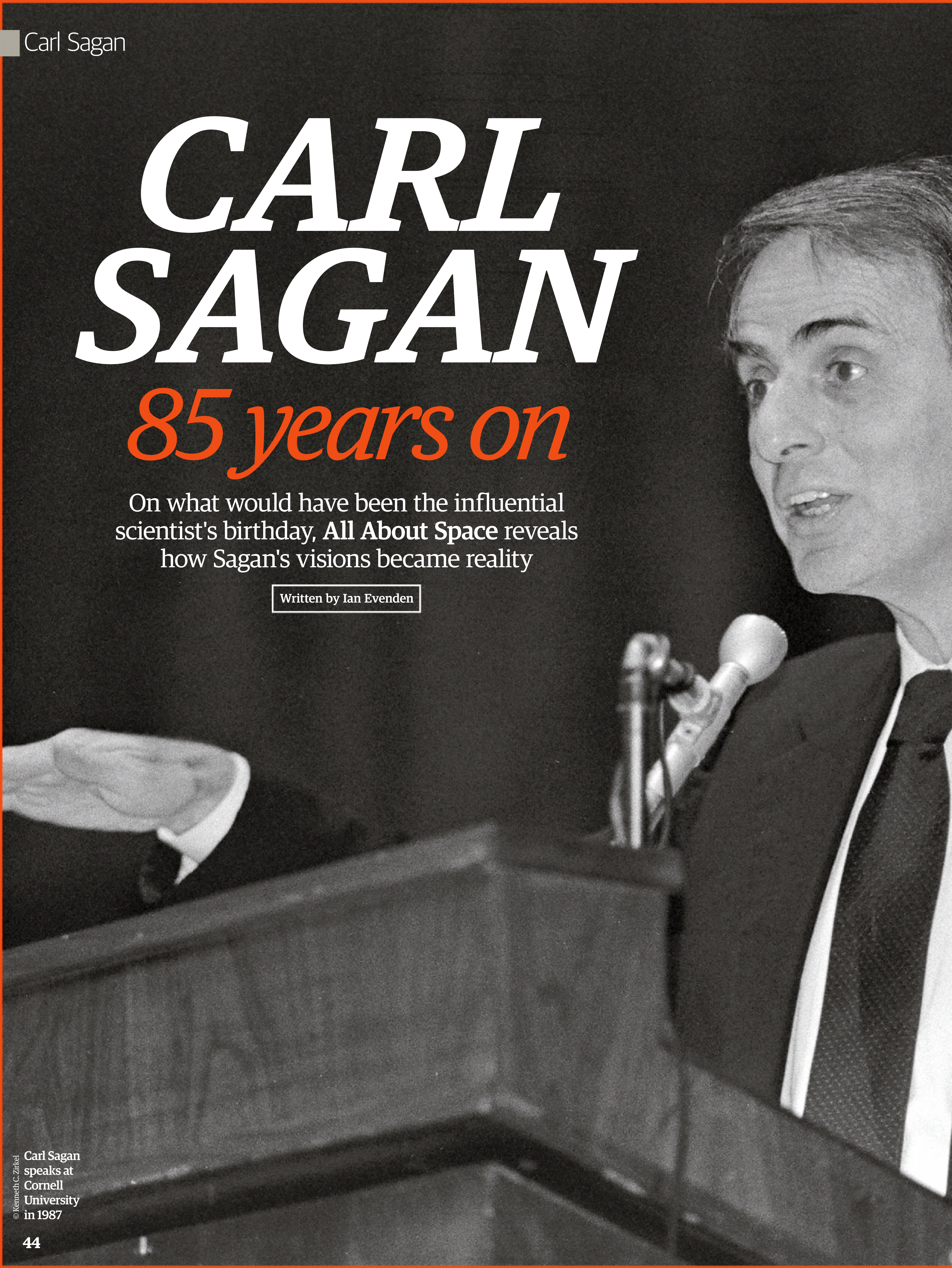
The Van Eyck crater is just one of the many enormous craters on Mercury

CARL SAGAN

85 years on

On what would have been the influential scientist's birthday, **All About Space** reveals how Sagan's visions became reality

Written by Ian Evenden



Carl Sagan speaks at Cornell University in 1987

© Kenneth C. Zirkel

“As a boy Kepler had been captured by a vision of cosmic splendour, a harmony of the worlds which he sought so tirelessly all his life”

Cosmos: A Personal Voyage

Sagan’s admiration of Johannes Kepler, the 16th to 17th century German astronomer who formulated laws of planetary motion and provided some of the work Newton’s theory of universal gravitation would be built upon, is shared by many at NASA, it seems. Sagan was particularly prophetic here, speaking of Kepler seeking worlds his entire life, as it was the Kepler space telescope, named after the astronomer, that would have this as its mission.

The spacecraft, now retired, was launched in 2009 with a mission to survey a small portion of the Milky Way for Earth-sized exoplanets in or near the habitable zone around their host stars. Not only did Kepler discover 2,662 exoplanets, having surveyed over half a million stars, but it kept working for 9.6 years, far in excess of its initial 3.5-year life expectancy. Even when its reaction wheels had failed, robbing it of the accuracy to collect exoplanet data, Kepler kept on working, its new mission to search a larger area of the galaxy for supernovae, as well as looking within the Solar System for asteroids and comets.

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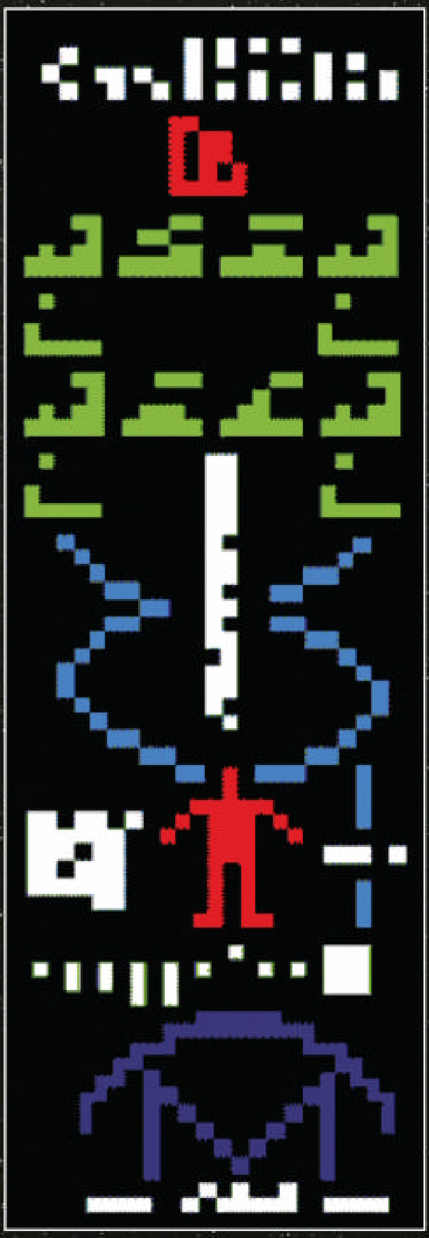
Above: The Kepler mission blasts off on 7 March 2009

Left: The Arecibo message, sent from Puerto Rico in 1974



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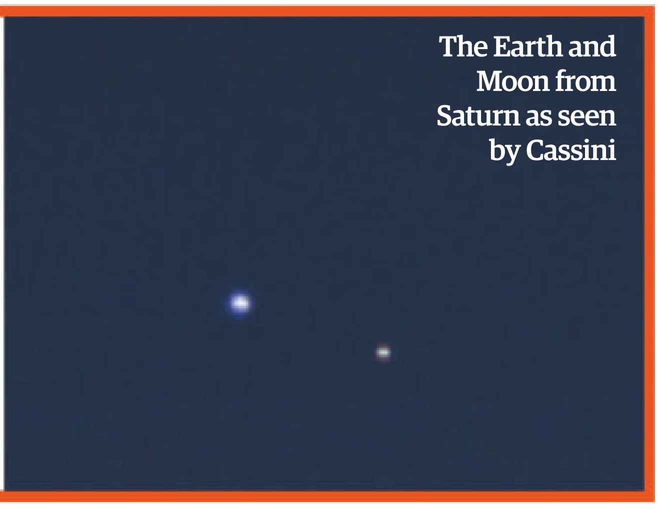
“It is easy to create an interstellar radio message which can be recognised as emanating unambiguously from intelligent beings”

***Smithsonian* magazine, May 1978**

Just four years before Sagan’s claim, a message was sent from the Arecibo Observatory in Puerto Rico in the direction of the globular star cluster M13. It consisted of the numbers one to ten; information about the Earth, humans and our Solar System plus the atomic numbers of the elements that make up DNA. Designed to be easily read and interpreted, it will still take 25,000 years for it to reach the cluster, with another 25,000 for any reply from intelligent life to be received. M13 was chosen because it was in the right place in the sky at the time the observatory was reopening after remodelling work. Since then, however, further messages have been sent to Sun-like stars with exoplanets, including two – in 2008 and 2009 – to the Gliese 581 system just 20 light years away and containing what at the time were the most Earth-like exoplanets known.

“Astronomically, the USSR and the United States are the same place” *Cosmos*

Sagan is writing about the Cold War here. He had a lot to say on the matter of nuclear weapons, describing the US/Soviet face-off as two enemies in a room awash with gasoline, the one with 9,000 matches worrying that the one with 7,000 was getting ahead. As a broader statement on human conflict, however, it’s absolutely timeless. No matter how deeply we are divided over matters of politics, ideology or religion, we all live together on a tiny speck of dust in a cold, indifferent universe. By showing that if you have a distant enough viewpoint, both sides in the conflict appear the same, he’s commenting on the futility of war, something he described as “murder writ large”, and the need for us to come together as a species in harmony with our planet.



The Earth and Moon from Saturn as seen by Cassini

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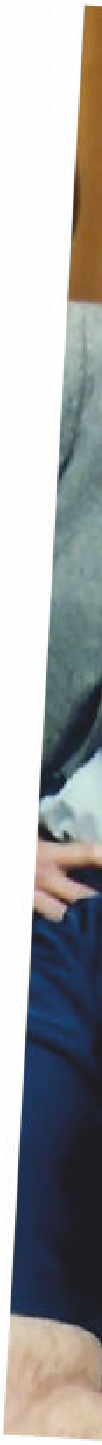
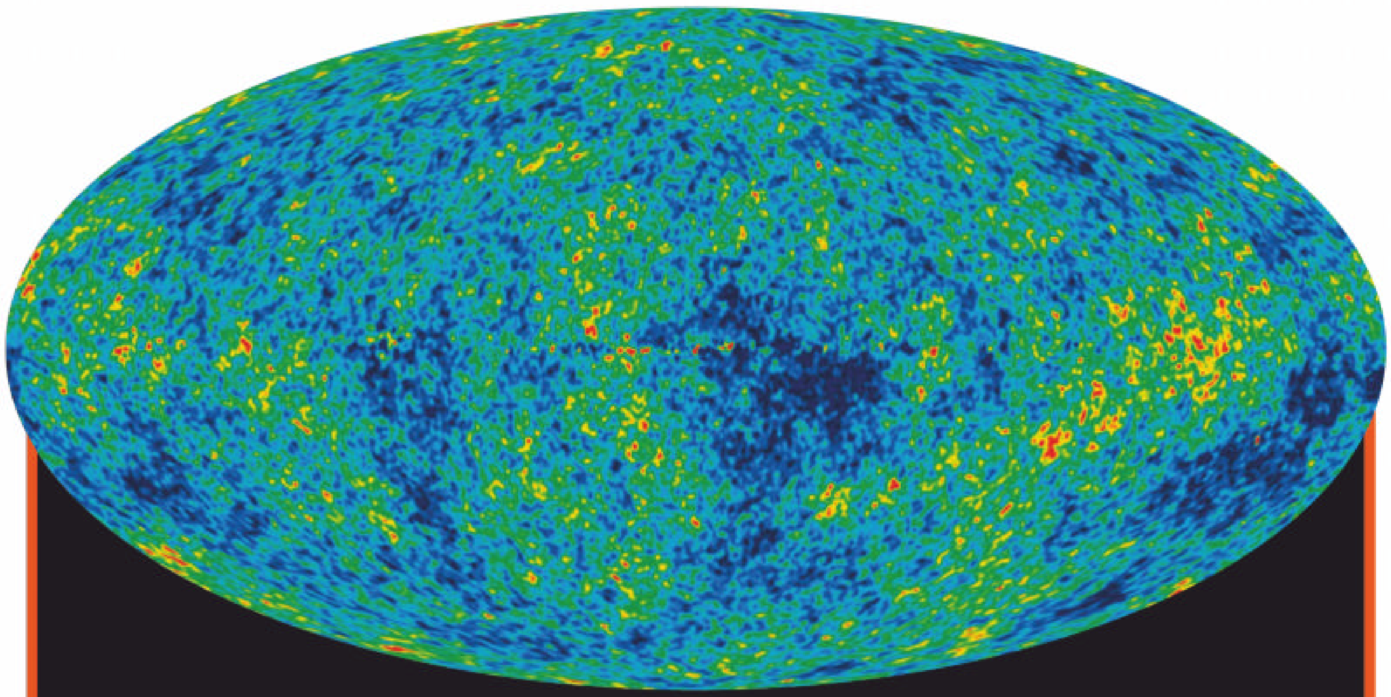
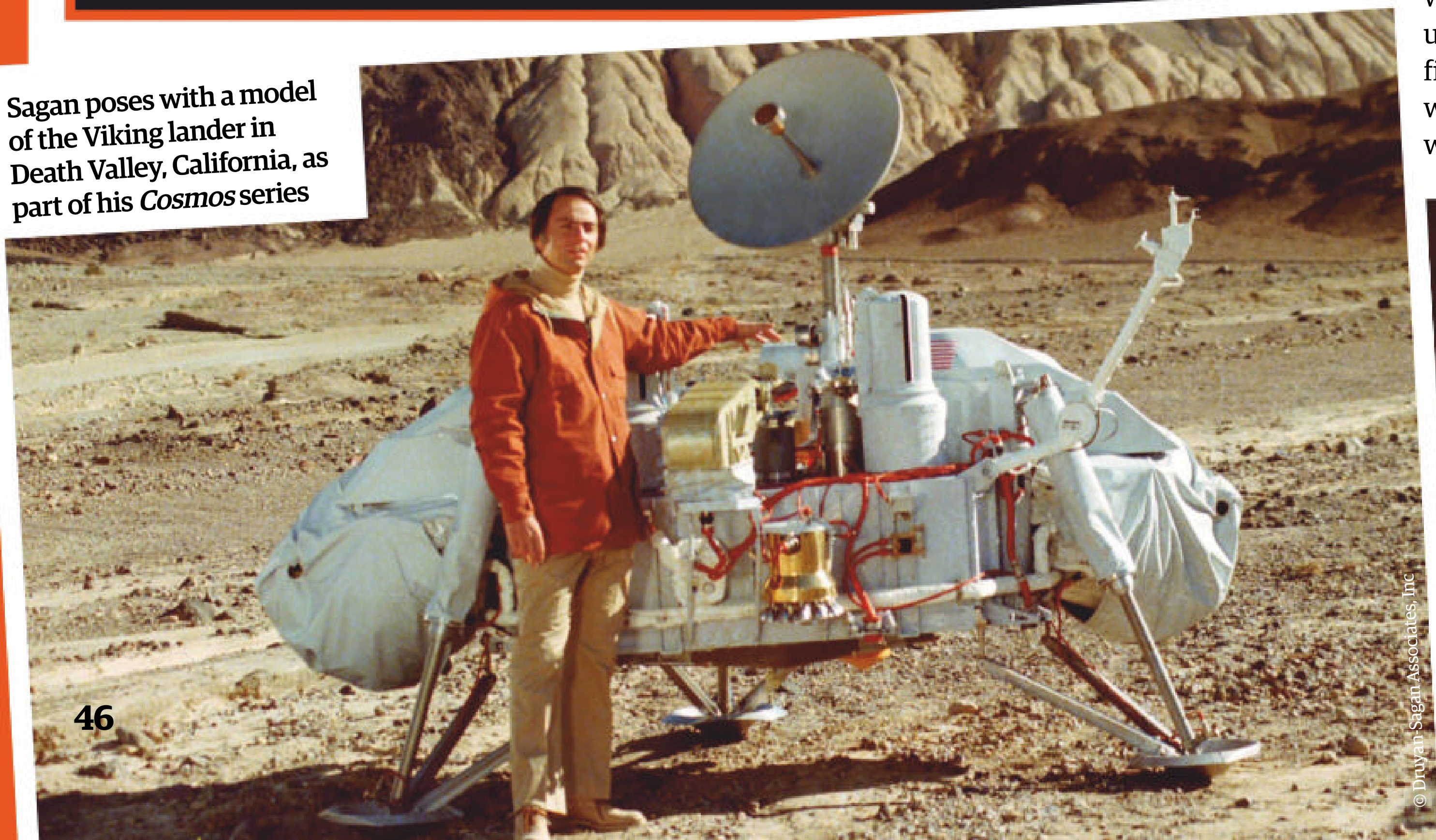




“The cosmos is all that is or ever was or ever will be” *Cosmos*

Assuming Sagan is using ‘cosmos’ here to mean the universe, he might not be entirely correct. If we are trapped within our universe and are unable to even see out of it, then this may well be seen as correct. However, we are able to hypothesise situations in which there could be more than one cosmos. The many-worlds interpretation of quantum mechanics, for example, had been around for 23 years when Sagan wrote those words in his book’s introduction. Since then we’ve seen research into the shape of the universe, into whether it really is infinite or a bubble nestled alongside others. Stephen Hawking’s final paper, published in 2018, aimed to test a theory that proposes parallel universes, and predicts a period before the Big Bang when time was like ‘a sphere without edges’ instead of the directional arrow we’re used to. In string theory - an attempt to merge quantum mechanics and general relativity - we could be part of a ten-dimensional multiverse with infinite universes governed by different physical laws. Include string theory offshoot M-theory - Hawking’s favourite candidate for a complete theory of the universe - and the number of dimensions rises to 11. Of course, if Sagan used ‘cosmos’ to mean ‘multiverse’, then he’s completely right.



Sagan poses with a model of the Viking lander in Death Valley, California, as part of his *Cosmos* series

© Druyan Sagan Associates, Inc

“We don't yet know whether the universe is open or closed. More than that, there are a few astronomers who doubt that the redshift of distant galaxies is due to the Doppler effect, who are sceptical of the expanding universe and the Big Bang” *Cosmos: A Personal Voyage*

The shape of the universe - whether it’s flat and infinite, curves in a way that means its edges must somehow meet or curves into dimensions we cannot appreciate - also tells us about its eventual fate, and has been the subject of much debate and experiment. If the shape is closed gravity will eventually stop its expansion, and it will contract back to a singularity. Unless, that is, dark energy overpowers gravity and it keeps expanding forever.

If the shape is open, dark energy will overpower gravity and it will expand forever, perhaps even overcoming the binding forces between individual particles. If the shape is flat - and this is currently best supported by experimental and observational evidence - then expansion continues forever, but its rate decelerates until dark energy once again takes over and it tears itself apart. As for those who doubt the Big Bang and the expansion of the universe, there’s probably a reason these ideas are filed under ‘non-standard cosmology’. However, with new experimental and observational data, who knows what can become ‘standard’?

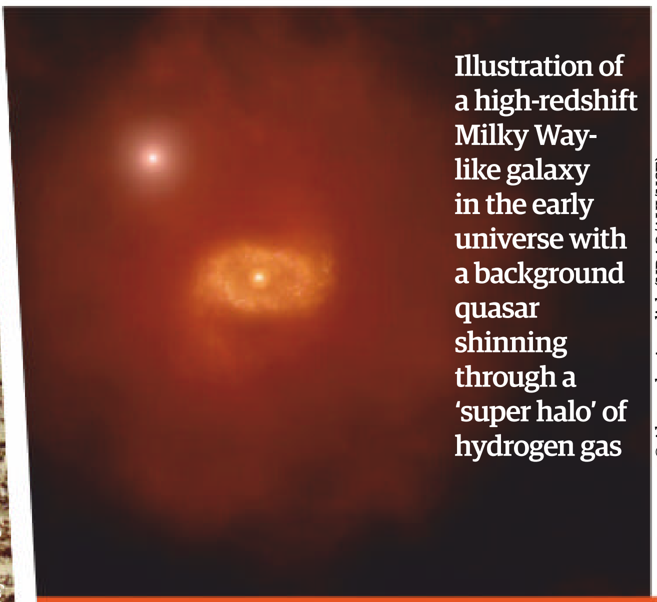


Illustration of a high-redshift Milky Way-like galaxy in the early universe with a background quasar shinning through a ‘super halo’ of hydrogen gas

© Alexandra Angelich (NRAO/AUI/NSF)

Carl Sagan, Bruce Murray and Louis Friedman, the founders of the Planetary Society, at the time of signing the papers formally incorporating the organisation. The fourth person is Harry Ashmore, an advisor who greatly helped in the founding of the Society

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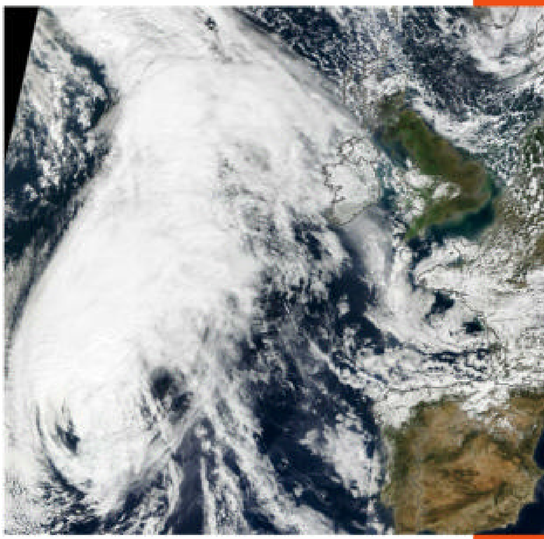
"Those who are sceptical about carbon dioxide greenhouse warming might profitably note the massive greenhouse effect on Venus"

Pale Blue Dot: A Vision of the Human Future in Space



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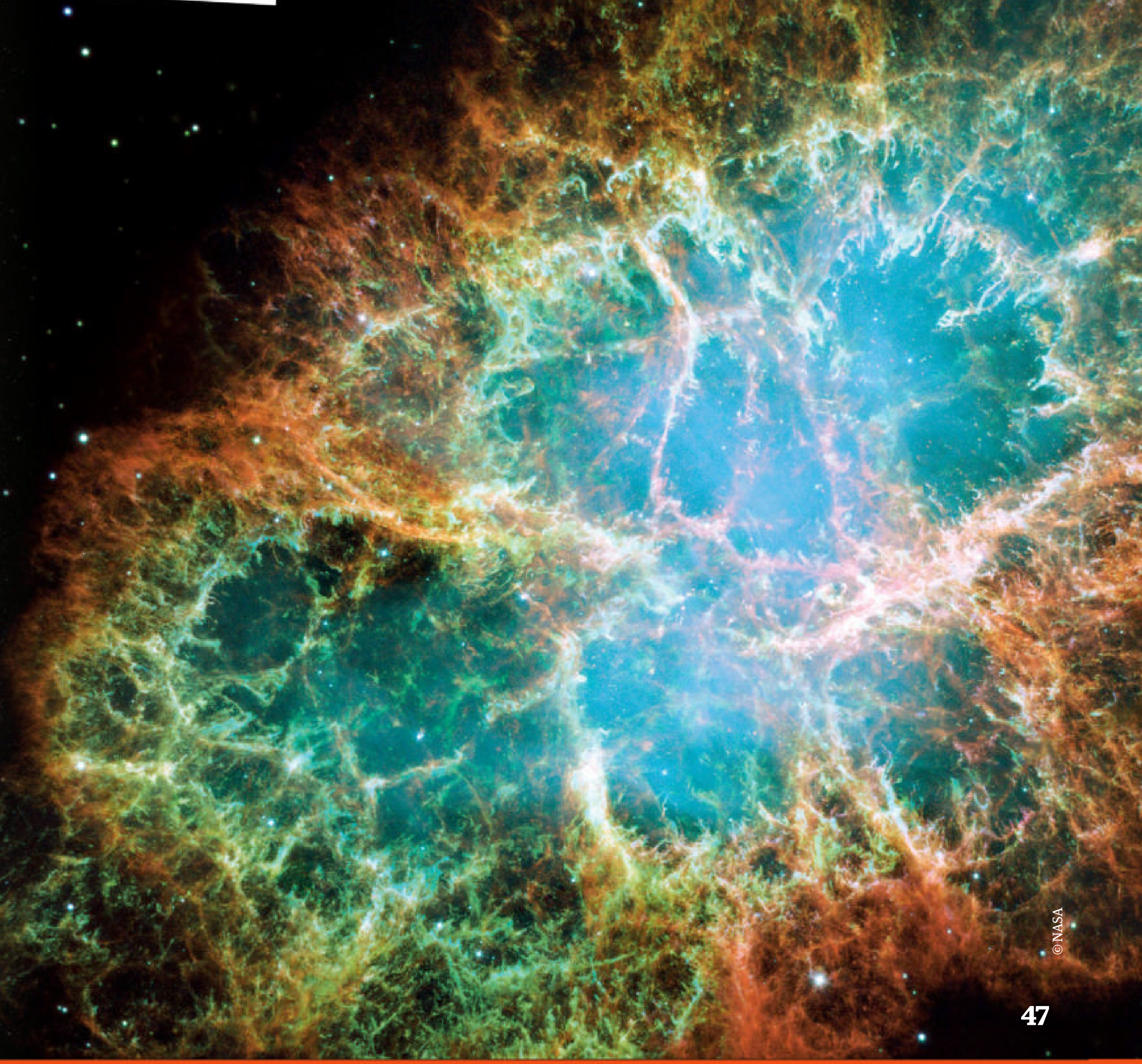
A quote that seems extremely pertinent today, Sagan goes on to deride those who claim that the greenhouse effect on Earth is somehow a 'hoax'. NASA's Earth-observing satellites have been publishing their results since 1999 as the NASA Earth Observatory. Recently they have recorded the second-lowest level of Arctic sea ice, Cyclone Hikka hitting Oman, dust storms in southern Africa, unusually heavy snow in Montana and Canada and the remains of Hurricane Lorenzo approaching Ireland after travelling further north and east across the Atlantic than any previous storm of the same strength. NASA's Earth Observing System, made up of satellites launched from 1966 onwards, provides much of the data. Only ten satellites, the oldest having launched in 1999, still have active missions, but further missions, including some based on the ISS, are planned. The European Space Agency also launches Earth-observing satellites, with the Far-infrared Outgoing Radiation Understanding and Monitoring (FORUM) mission to measure the radiation emitted by Earth into space selected in September for a launch in 2026.

"The cosmos is also within us. We're made of star-stuff. We are a way for the cosmos to know itself"

Cosmos: A Personal Voyage

What Sagan is getting at here is stellar or supernova nucleosynthesis, the creation of heavy elements, many of which end up inside our bodies, during the lives and death explosions of gigantic stars. The Big Bang produced hydrogen, helium and lithium, plus a few heavier isotopes that decayed back into helium and lithium.

This was enough to produce stars, which fuse hydrogen into more helium, and as the stars heat up heavier elements are produced, including the carbon and oxygen essential for life on Earth. This chain keeps going until it reaches iron, the first element that requires more energy to fuse than the process produces. Anything heavier than iron must be produced in an environment with greater heat and pressure than the interior of a star, and an exploding massive star is just such a place. Everything around us and within us, apart from hydrogen, helium and lithium, was produced in the fusion furnaces within stars, meaning we are inseparable from the universe around us.



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“Imagine we could accelerate continuously at 1g - what we're comfortable with on good old terra firma - to the midpoint of our voyage, and decelerate continuously at 1g until we arrive at our destination. It would take a day to get to Mars, a week-and-a-half to Pluto, a year to the Oort Cloud and a few years to the nearest stars”

Pale Blue Dot: A Vision of the Human Future in Space

Alternatives to the solid- and liquid-fuelled booster rockets and gas thrusters we rely on to propel our spacecraft once in space are being actively sought. Solar sails, which harness the energy of the Sun for movement, have been tested, with the Japanese IKAROS probe heading to Venus in 2010, and the Breakthrough Starshot project is planning a fleet of tiny probes sent to Proxima Centauri by lightsail, pushed by Earth-based lasers for an initial acceleration burst of 10,000g. Slowing down at the destination would be difficult, however. The lack of friction in space means once you've accelerated to a speed you stick to it, hence Sagan's careful wording of acceleration and deceleration. Other ideas have included the crazy-sounding 1958 Orion project that propelled spacecraft by exploding nuclear bombs behind them and riding the shockwave.

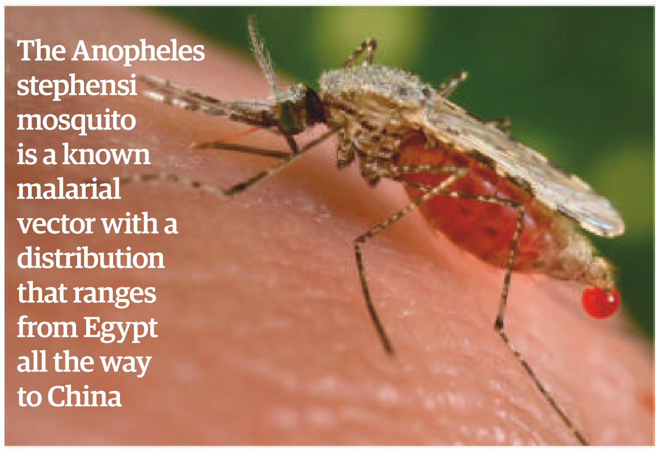
Ion thrusters - possibly powered by a nuclear reactor - that shoot charged particles out like a rocket have been tested on the Deep Space 1, Dawn and BepiColombo missions, among others. Sagan's dream of a smooth 1g acceleration and deceleration, however, is still some distance away.

Above: The ESA's BepiColombo mission will use solar-powered ion thrusters as part of its flybys of Venus and Mercury between 2020 and 2025

“Advances in medicine and agriculture have saved vastly more lives than have been lost in all the wars in history”

The Demon-Haunted World: Science as a Candle in the Dark

Advances in medicine continue to this day, though perhaps nothing with the wide-ranging effects of the discovery of antibiotics or antiseptics. Take the mosquito: this tiny flying bloodsucker was responsible for the deaths of a million people in 2018 alone, according to the American Mosquito Control Association, and could have killed over 50 billion humans over the last 100,000 years. The culprit isn't the mosquito at all, but parasites and viruses they carry in their digestive system. The best known, Malaria, is a parasite with a life cycle that takes it from mosquito to human and back again. Modern medicine is fighting back, however, with a vaccine undergoing pilot trials in Malawi, Ghana and Kenya this year.



The Anopheles stephensi mosquito is a known malarial vector with a distribution that ranges from Egypt all the way to China

© Centers for Disease Control and Prevention

“I stress that the universe is made mostly of nothing, that something is the exception”

The Varieties of Scientific Experience: A Personal View of the Search for God

The distribution of matter in the universe is clearer to us today than it was when Sagan was writing. Not only are the distances between clumps of matter - galaxies - absolutely huge, but 95 per cent of the universe is comprised of something we can't detect in any way. Dark matter, which makes up 27 per cent of the total mass-energy of the universe, can at least be observed through its gravitational effects. Dark energy - 68 per cent of the mass-energy of the universe - is even more mysterious, existing only as the most well-accepted hypothesis to explain observations that the universe is expanding at an accelerating rate. These percentages come in part from Planck Space Telescope data released in 2013, so Sagan couldn't have known of them, but dark matter can trace its roots back to the 1920s and 1930s, when astronomers such as Jan Oort and Fritz Zwicky were studying local stars and galactic clusters respectively. Dark energy has its origins in Einstein's calculations for general relativity, proposed as a way to balance out gravity to keep the universe static. This is one of the most hotly contested areas of astronomical research, and promises great revelations.

This happy image from the Hubble Space Telescope shows the view of distant galaxies being gravitationally lensed by a large mass in between. Predicted by Einstein, images such as this are evidence for mass we cannot see

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Left: Sagan's wife and collaborator, Ann Druyan, edited his final collection of essays and was instrumental in bringing *Cosmos* to television

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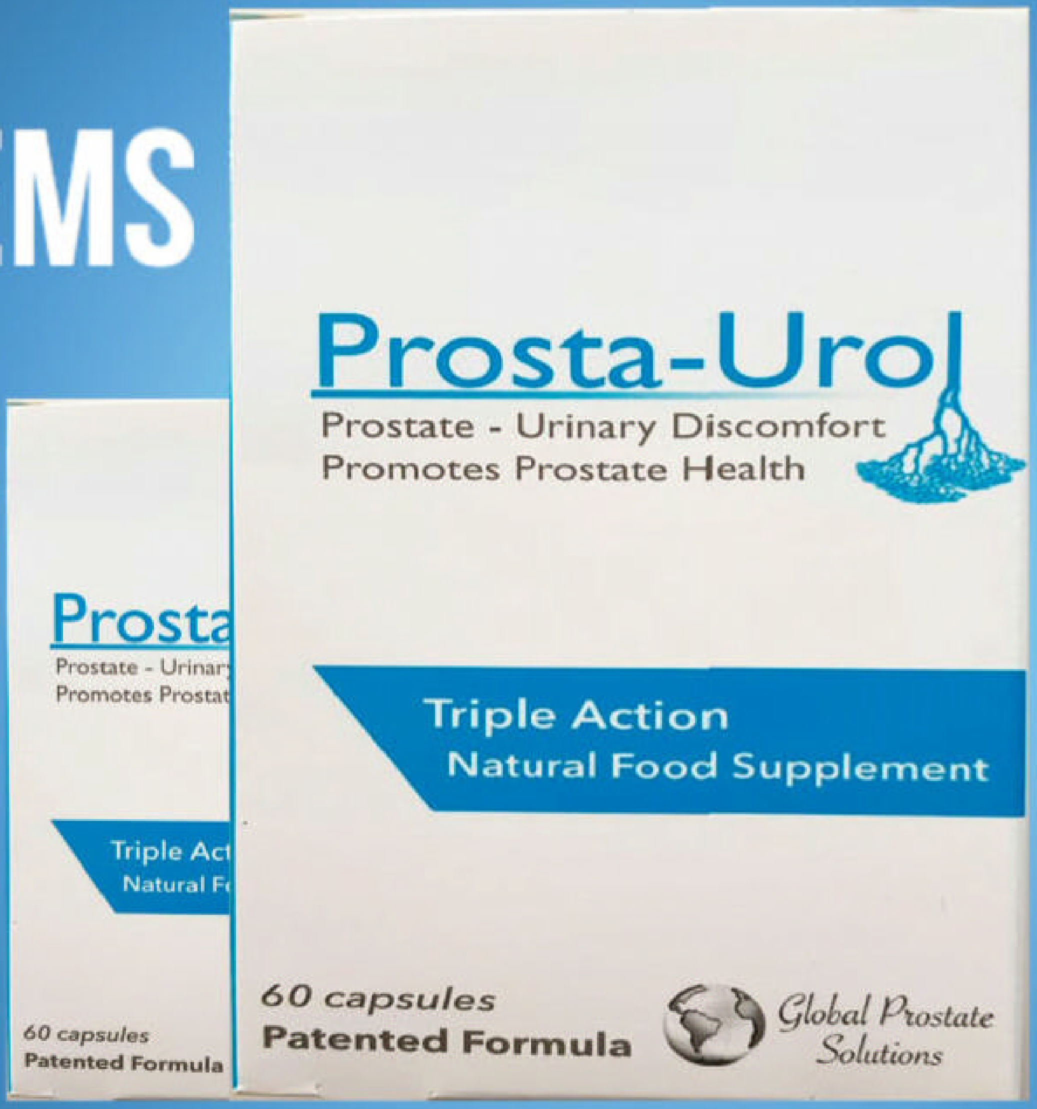

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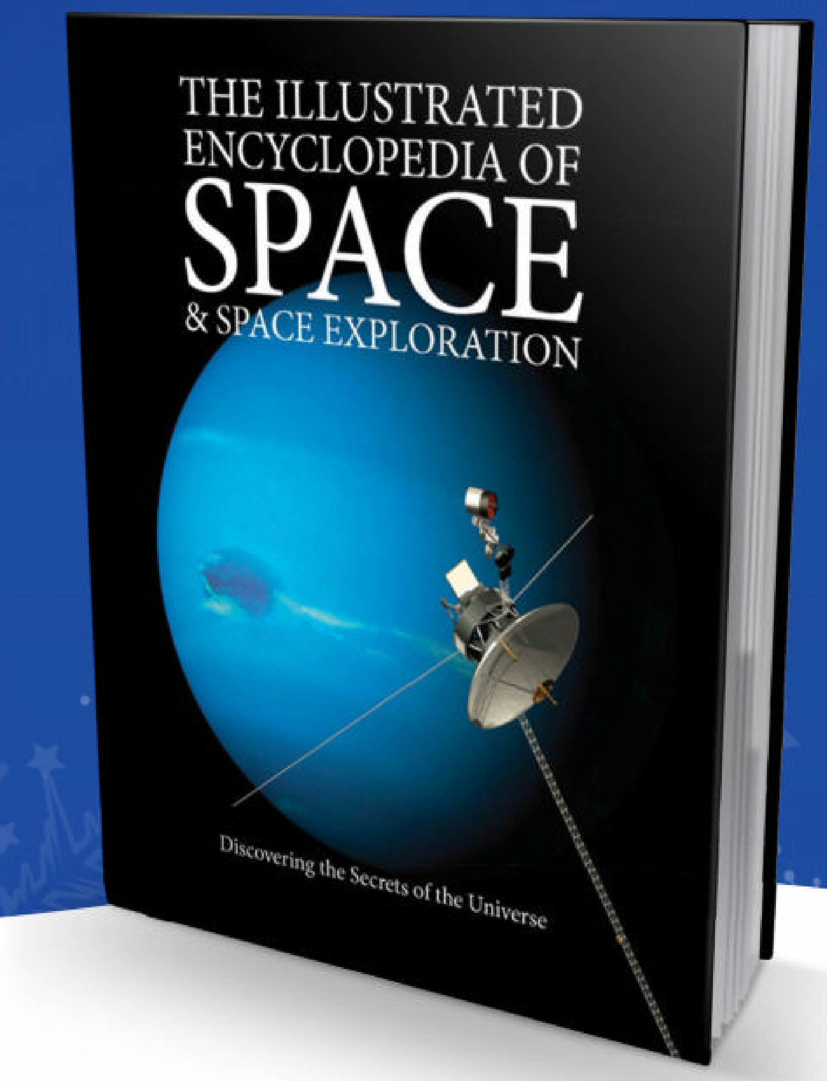
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SPACE ROCKS

BEHIND THE SCENES

All About Space returned to the annual space-inspired extravaganza to meet the celebrities and scientists who put on quite the show

On 21 September 2019, Space Rocks returned to indigo at The O2 Arena in London, United Kingdom, for a second year, and it didn't disappoint. The **All About Space** team had the pleasure of attending this event of space, science, science-fiction and music all rolled into one. Not only that, we had the opportunity to have a peak behind the curtain and talk to some of the people who made this event another stupendous, highly enjoyable and highly educational day of family fun.

Space Rocks, presented in association with the European Space Agency (ESA), had great success in its previous year, winning 'Event of the Year' at the *Prog* Music Awards, and was also nominated for a Sir Arthur Clarke Award by the British Interplanetary Society. This time it was back with some old faces, some new faces and the gob-smacked faces staring at the stage in front of them.

The day began with the Space Academy session, where some of the smartest minds in the industry gave talks on their specialised subjects. The session was hosted by famed actor Jason Isaacs, who played Lucius Malfoy in the *Harry Potter* films, Captain Gabriel Lorca in *Star Trek: Discovery* and many more. When asked how he found himself hosting the first session at Space Rocks, he answered: "I had the amazing privilege of meeting people from NASA and the ESA, and I met Mark [McCaughrean] at a convention somewhere. He said, 'How interested are you in space?' And I went, 'I'm interested in asking really stupid questions to really smart people.' He went, 'That's exactly what we need.'"

Isaacs also spoke about the event in glowing terms, saying: "I don't think there are other events that exist where people who work in space - and every aspect of space - open the doors to the public and really pull the curtain back so that it really seems not only less mysterious, but attainable, so that generations of young people watching it can go, 'You know what, I could do that.'"

And that's exactly what the first session was all about. People such as planetary scientist Suzie Imber, award-winning sci-fi visual effects guru Paul Franklin, space engineer Kate Underhill, space robotics engineer Shahrzad Timman and ESA astronaut Tim Peake all gave remarkable talks about what has been done in space and science-fiction, what is currently happening and, most importantly, what there is to be excited about.

Left: Space Rocks was held at indigo at The O2 Arena in London, UK

Below: Paul Franklin has won both Oscars and BAFTAs for his Visual FX work on *Inception* and *Interstellar*

"I loved the audience this morning. I gave a talk about Mercury to a young audience, and it was really nice to inspire some kids that were listening carefully. It's a different audience than my normal. I'm used to lecturing students and I give other talks, but it's different giving it to families, and I really like that side of Space Rocks," said Imber.

"It's been fantastic at Space Rocks. The combination of scientists, art and astronauts – Tim Peake is here – a lot of people from the ESA telling us about how they made their rockets and space missions to Mercury and beyond. It's fantastic," said Franklin. When asked if he'd ever experienced an event such as this, he replied: "No, I've never been to anything quite like this before. There are space and science conferences that maybe try and do something similar, but it's very much aimed at scientists and people who are in this world. Space Rocks is accessible to anyone. It's a fantastic crowd of parents, children, teenagers and interested adults."

From Space Academy to Space Lab, this next session dove headfirst into a diverse range of topics with some new faces, including climate change, science-fiction, black holes and other exotic mysteries throughout the universe. This event was hosted by renowned BBC presenter Dallas Campbell, making his Space Rocks return, and kicked off with Tim Peake talking to leading climate scientist Tamsin Edwards about climate change.

All About Space had a chance to chat with Peake, who was very excited about the return and growth of Space Rocks. "Space Rocks is going from strength to strength. I think whenever you bring like-minded people together, whether they're interested in space or music or culture or arts, then it always makes for a fantastic event," he said. When asked if he thought he had inspired any young astronauts he replied: "I hope so. I mean, it's their future. What I was trying to do is just say how exciting it is. For 20 years we've been going to low-Earth orbit on a space

> "I gave a talk about Mercury to a young audience, and it was really nice to inspire some kids" **Suzie Imber**

station, and that's exciting in terms of the science and what we're doing. But really, this is the next step - it is coming along in the next five years - we are building another orbital outpost around the Moon in order to service lunar surface operations. I mean, how exciting is that? Going back to the Moon with a vision that only ten years beyond that we'll be going off to the Red Planet."

Next Campbell introduced *The Expanse* actress Dominique Tipper and science communicator Sue Nelson to talk about the past, present and future of human space exploration. With her recent book detailing the struggle of women trying to get into space in the 1960s, *Wally Funk's Race for Space*, Nelson spoke about how she wanted to impart an important message to the younger, female aspiring astronauts in the crowd. "[My message] will be a mix of a little bit of letting them know there have been obstacles, but not enough to put them off. I think it's important to highlight the fact that women have done amazing things in space and have always done. A lot of people mistakenly think that Apollo was pretty much a male-only endeavour. Yet there were so many women behind the scenes as engineers, and in other professions, who actually helped make that happen. I hope one child in that room comes out thinking, 'Wow! There are jobs for me now, with the new commercial spaceflight industry as well as with the ESA and NASA,'" she explained.

After followed BBC *The Sky at Night* presenter Chris Lintott and award-winning science author Lucy Hawking discussing the wonders and mysteries of the universe, including black holes,

Left: The Space Rocks team celebrate another successful year and a great day

Below left: Dominique Tipper (left) and Sue Nelson (right) spoke eloquently about space exploration in all its tenses

Below: Session two, Space Lab, also celebrated the recent Apollo 11 anniversary

A JOURNEY THAT BEGINS WHERE EVERYTHING ENDS
THE BLACK HOLE
SPACE ROCKS 2019
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Above: Science-fiction versus actual science was an intriguing topic of discussion at Space Rocks

Left: Suzie Imber spoke to the Space Rocks audience about the planet Mercury and the mission heading there now, BepiColombo

exoplanets and so much more. Anna Phoebe, a violinist and composer, performed an exhilarating piece of music, taking the audience on a musical voyage through the Solar System. This certainly had one of the panellists excited before she went on stage: "I'm very much looking forward to the musical piece by Anna. She's doing a piece of music which is inspired by the Earth observations from ESA satellites. It's a musical piece based on climate change," said Lucy Hawking. "She said one of the inspirations for her was this idea that the space age allows us to look back at ourselves, which I've always put in all my books. One of the really important things about being able to travel away from the Earth is that it gives us the ability to look back and see that perfect image of the whole world. And that's such a powerful image, especially right now when we're so divided."

To finish the second session was the discussion Space: Stranger Than Fiction

between Jason Isaacs and the co-founder of Space Rocks and senior science advisor for the ESA Mark McCaughrean. We had the chance to catch up with Mark, and asked how this year compared to last year. "It's been an enormous amount of work over the last six months pulling it together. Obviously we wanted to mix it up with the people we have on stage and musicians, but also the scientists and the engineers. Some of the connections didn't exist last year. For example, Jason Isaacs is here. I actually only met him soon after the first Space Rocks at a science-fiction convention," said McCaughrean. "We've got a very good mix. Younger people, older people, men and women, different experiences, different backgrounds. I'm actually thrilled that we've made a step up. It's frantically busy as one of the organisers here, but it's good."

Thirdly and finally, the day-long event ended with a session that put the 'rocks' in Space Rocks. It included live performances from musicians and bands, bringing a visionary edge to it with music inspired by the cosmos. These musicians included Anathema, doing a unique set they called the Space Between Us, Australian rockers Voyager and the Mancunian trio Amplifier, all bringing a unique and lively performance to round the amazing day off.

After another day of fun, imagination and smiling faces, Space Rocks reached its conclusion. Some may be thinking, what's next for the event? Will they continue doing what they're doing? Will there be even more? Well, McCaughrean did elude to big things to come. "I think what's been interesting for me at the ESA is that I have the opportunity to show what we've done with film, with photographs and with some of the music to our various scientific committees from the 22 member states. I can show them what we do at Space Rocks and lots of those countries have said, 'We want you to come and do it for us now,'" he said.

"Obviously 22 countries can take a while to get around, but there's a lot of enthusiasm for doing things like Space Rocks in the big countries like France, Germany and Italy, but also places like Poland and Romania and so on. I think it's going to take a lot of effort, because we've got to ramp it up in terms of connecting with science speakers and bands. It'll be partnerships with people locally. But now there's a huge future ahead."

Right: Tamsin Edwards is a leading expert in climate sciences at King's College London

Below: Tim Peake (left), Tamsin Edwards (centre) and Dallas Campbell (right) discussed the effects of climate change viewed from the ground and in space

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CAVEMEN IN SPACE

Underground caverns in our Solar System could serve as a means to explore other worlds - and safe enough to send humans

Reported by James Romero

© Getty

"The first thing that comes to my mind when I think of a cave is home," says Martin Gasser, a speleologist, or cave scientist, who along with his wife, geologist Christa Feucht, is a leading expert on the subterranean worlds below western Iceland. After two decades exploring the region, one cave has become the focus of their attention. Surtshellir is the longest in the country. Its mile of magma- and basalt-walled tunnels has been used as a hideout for bandits since the 10th century.

This infamy has come at a price. Over the centuries the spectacular stalagmites and stalactites have been damaged and stolen by souvenir hunters. Ordinarily such vandalism would dishearten a speleologist. Yet this was exactly what Gasser and Feucht were looking for.

Despite spending up to a week at a time underground exploring Surtshellir, the couple always had an eye towards the heavens. Over the last ten years high-resolution cameras on Martian and lunar orbiters have spotted signs of vast underground cave systems - cave systems which were familiar to them. "It's only a short step to the Moon and Mars when you are talking about the geology of Iceland," says Feucht.

In response to these extraterrestrial cave discoveries, space agencies have begun dreaming up ingenious methods to explore and make homely these natural shelters for off-world living. What Gasser and Feucht saw in the vandalised Surtshellir cave was an opportunity to make the best of a bad situation. At the National Geographic Explorers Festival in 2016, they proposed the creation of a testing facility for the robotic explorers and habitation units required for human residence under another world. In the audience was noted American explorer Mike Dunn. Soon after hearing their talk, Dunn set up the company 4th Planet Logistics to develop and test cave technology "for eventual lunar-Mars habitation". Today Gasser and Feucht are Dunn's geological consultant and operational coordinator in Europe.

Right: In May the US Department of Defense Subterranean Challenge competition opened, assessing new cave-exploring robots from JPL, Caltech, MIT and KAIST

© NASA/JPL-Caltech

The vision of Dunn, Gasser and Feucht is a far cry from initial interest in the subsurfaces of other worlds, inspired by lunar mining. The prophesied industry received a boost as it became clearer the Moon's more geologically active past may have done a lot of the tunnelling for them. A 2014 analysis by the Lunar Reconnaissance Orbiter camera team, led by Robert Wagner of Arizona State University, discovered 200 collapse windows into cavernous voids beneath. Soon after a Purdue team proposed these pits were our first glimpse of a vast underground network of lava tubes.

On Earth such tubes are carved out by subsurface lava flows, moving like a snake through rock. However, due to the Moon's lower gravity, the potential scale and range of these underground networks is huge. In orbit around Mars at a similar time, the Mars Reconnaissance Orbiter was finding more collapsed windows near the Red Planet's ancient volcanoes. For prospective space miners these pre-dug networks present a cost-effective route to any subsurface riches. However, for space agencies and adventurers driven by exploration rather than exploitation, the real potential is human habitation.

"On the Moon or Mars it would seem logical to use whatever existing environments are there so you don't have to expend time or money building a shelter," says Manfred von Ehrenfried, a former NASA flight controller whose latest book, *From Cave Man to Cave Martian*, was published during the earlier part of this year.

As well as time and cost savings, any pre-dug underground real estate offers protection from the constant stream of micrometeorites and high-energy particles raining down from above. In addition you can enjoy more stable temperatures, shelter from Martian dust storms and access to nutrient-rich volcanic regolith for growing food. As suspected, some of these spaces are huge. Two years ago the Japan Aerospace Exploration Agency (JAXA) discovered a 50-kilometre (31-mile) lava tube beneath the lunar surface.

Under Mars there is particular interest in caves as time capsules to reveal the planet's early formation, and whether it once hosted life – or even whether it still does. Periodic spikes in methane have been measured within the Martian atmosphere and traced underground. Some astrobiologists have suggested underground-dwelling, methane-producing microorganisms, like those found inside the Earth, as a possible source.

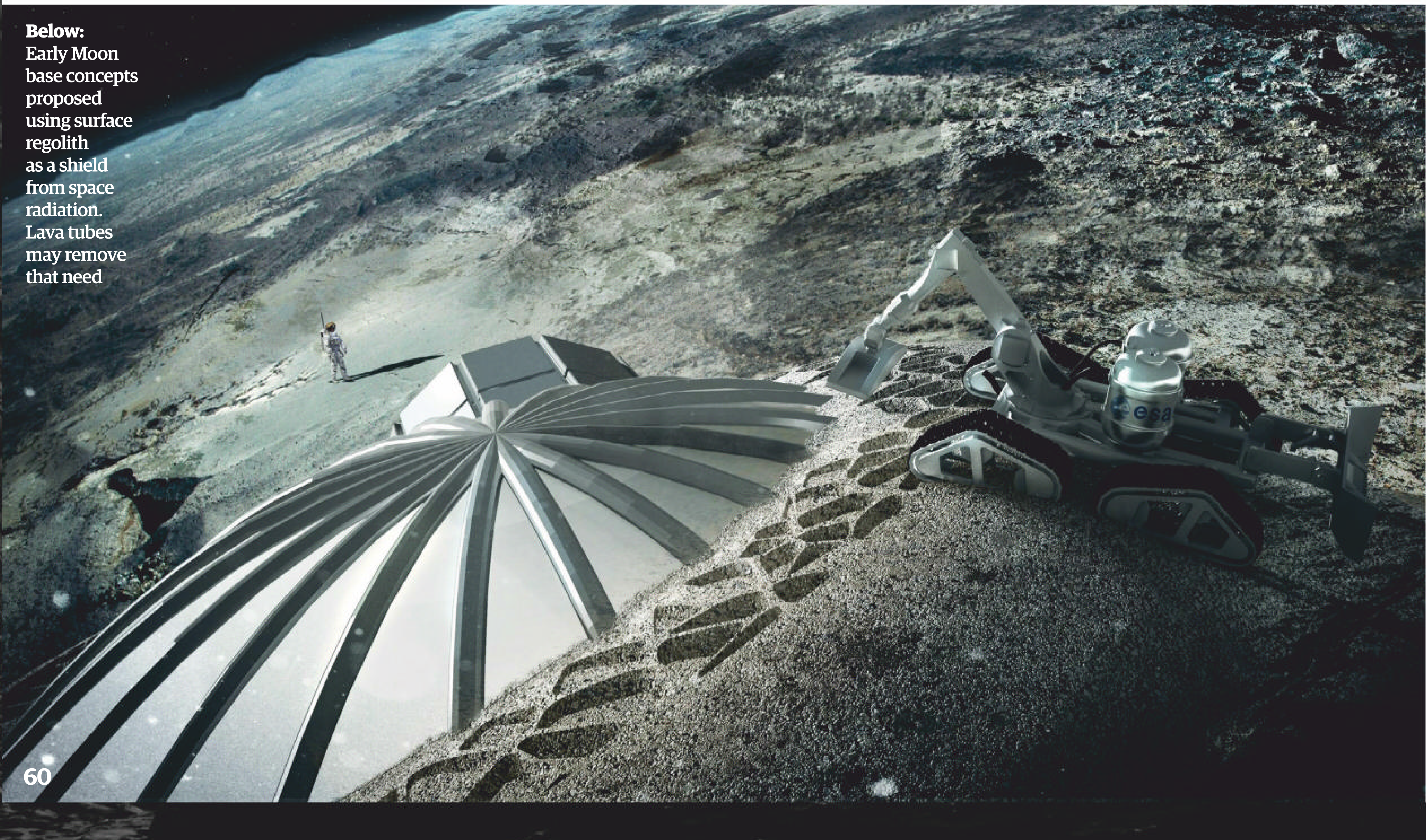
"There could be isolated organisms near old remnant volcanic activity. Or the next best thing is we find fossilised remains of past life," says Jekan Thanga, a space robotics expert, for whom the discovery of subsurface methane led to a focus on exploring lava tubes.

However, there are significant engineering challenges to entering the subsurface. A heavy rover driving up to the edge of an already once-collapsed ceiling raises obvious concerns, and that's before we get to a vertical descent of up to 100 metres (328 feet). Even if a rover makes it down in one piece, the cave floors are covered in rubble, posing mobility challenges. As a result, space agencies are on the lookout for new, innovative approaches. In May the latest US Department of Defense Subterranean Challenge competition opened, assessing new cave-exploring robots from NASA's Jet Propulsion Laboratory (JPL), Caltech, the Massachusetts Institute of Technology and KAIST. It followed the ESA's own open call for robots to explore the subsurface of the Moon.

One solution to pit-rim instability is to bypass the surface altogether. Dr Mark Robinson from Arizona State University has looked into aiming a lander directly into the pit. "That's the scariest of them all," says Thanga, due to the challenge of achieving the requisite entry descent and landing precision to drop into pits that are generally less than 100 metres (328 feet) wide. "But it's also probably one of the most thrilling too." Most other pit-exploration approaches fall into one of two categories: abseilers or jet-propelled gliders and hoppers.

The former has the advantage that the tethering cable can be engineered to relay power and communications to and from the surface lander. The JPL is currently pursuing this with the Axel Rover as part of its Moon Diver mission concept. However, once at the bottom, surface scramblers then risk getting stuck traversing the uneven cave floor. "They seem to always test this stuff on sand or gravely floors," says von Ehrenfried. "But in a

> "It's only a short step to the Moon and Mars when you are talking about the geology of Iceland" **Christa Feucht**



Below: Early Moon base concepts proposed using surface regolith as a shield from space radiation. Lava tubes may remove that need cave you have very little of this."

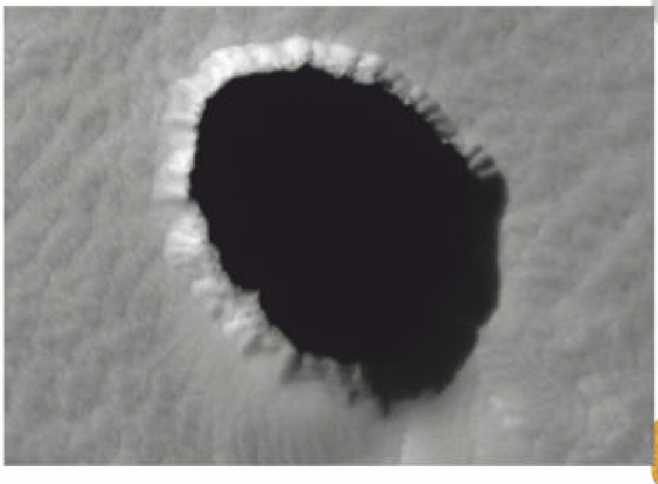
This challenge is why other robotics teams are taking to the air, or what passes for it on the Moon or Mars. This summer NASA's Mars 2020 rover was fitted with a small helicopter to explore subterranean channels. Back on Earth a project led by the Search for Extraterrestrial Intelligence (SETI) saw drones mapping Icelandic caves earlier this year with a view to future missions to the Moon.

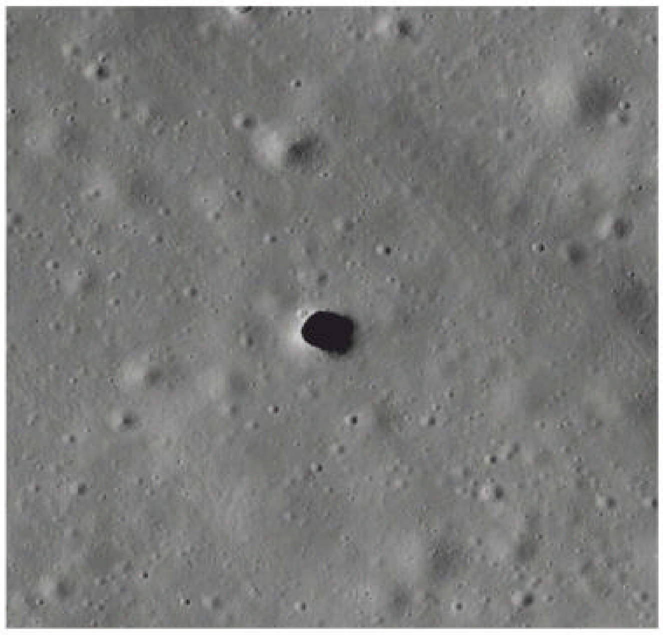
But the single flying explorer approach still carries quite a high risk. This is why microbot solutions, spreading the risk across an army of small, thruster-driven explorers, are receiving interest. The thrusters provide a soft landing, but can also power lateral exploration as the bots fan out. This ensures a greater mission range for any given amount of fuel, which is essential without solar power.

"Teams [of microbots] can also form bucket brigade teams, passing messages from one to another," says Thanga, who presented his own lunar microbot design, named the Spring Propelled Extreme Environment Robot (SPEER), at the IEEE Aerospace Conference 2019 in March.

SPEER includes a spring-powered launcher on the surface to catapult one lightweight, low-cost, spherical microbot into the pit at a time. The microbots, which would cost just $500 each to produce, have a total mass of one kilogram and include a camera and 3D laser scanners. Once on the cave floor the SPEER bots move around using thruster-powered hopping, an efficient method in low-gravity environments, especially with the addition of three-axis gyro stabilisers.

As Thanga's team build a prototype for field tests, he is realistic about the scope of any initial microbot

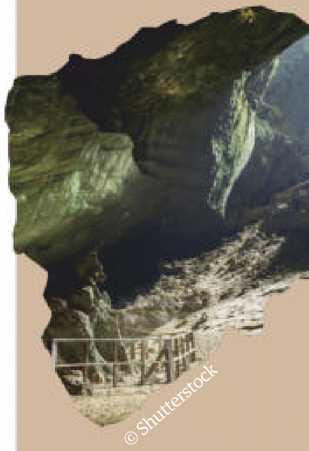




x2 © NASA

Alien caves

We have found evidence of subterranean environments under the surface of a number of Solar System worlds



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Earth

Earth's caves have provided a shelter for humans and our ancient ancestors for over a million years, as evidenced by fossilised remains and cave wall art. As well as lava tubes similar to those found on Mars and the Moon, Earth's atmospheric water cycles mean you also find caves within karst landscapes where water dissolves away limestone, creating a subterranean world of caverns, springs, aquifers and sinkholes.

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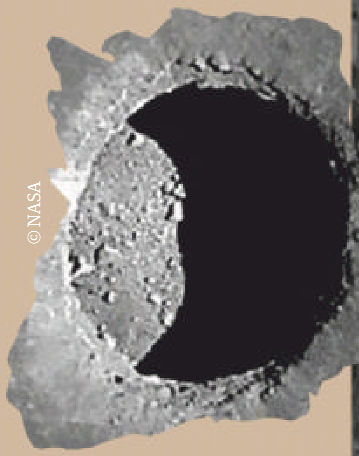
The Moon

Due to our Moon's lower gravity it was long suspected that subsurface lava flows might create extensive lava tube networks, far bigger than anything on Earth. In 2017 JAXA reported a discovery that seemed to support such a theory. It was an enormous 50-kilometre (31-mile) long, intact lava tube around the Marius Hills hole. The subsequent discovery of water ice beneath the Moon's southern pole might make exploration of the subsurface there the most realistic site for the first lunar base.



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Mars

The first evidence of Martian caves came from the three-metre-per-pixel resolution of the HiRISE camera on board the Mars Reconnaissance Orbiter, which found collapsed skylights near ancient volcanoes. Since their discovery, scientists have become interested in whether these rare windows into the Martian subsurface might settle the debate over whether life ever existed on the Red Planet, or whether it is still there. This interest increased after evidence emerged of periodic spikes in methane, which could originate underground. Some astrobiologists have suggested that microorganisms analogous to those we find on Earth could be a possible source.

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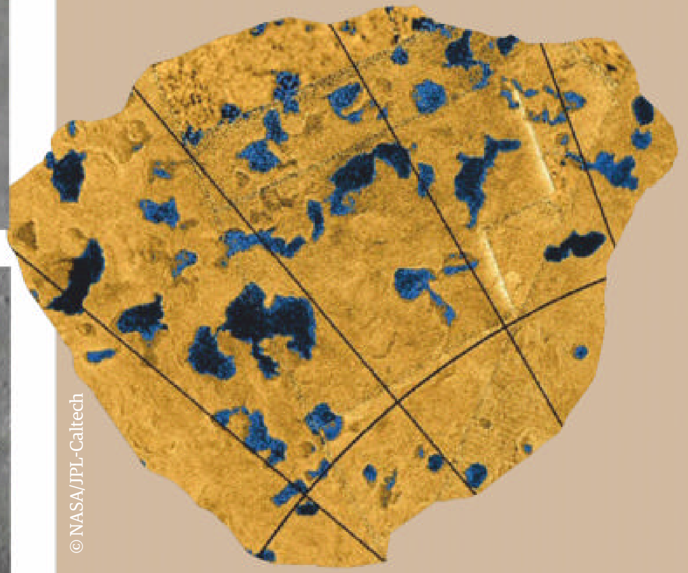

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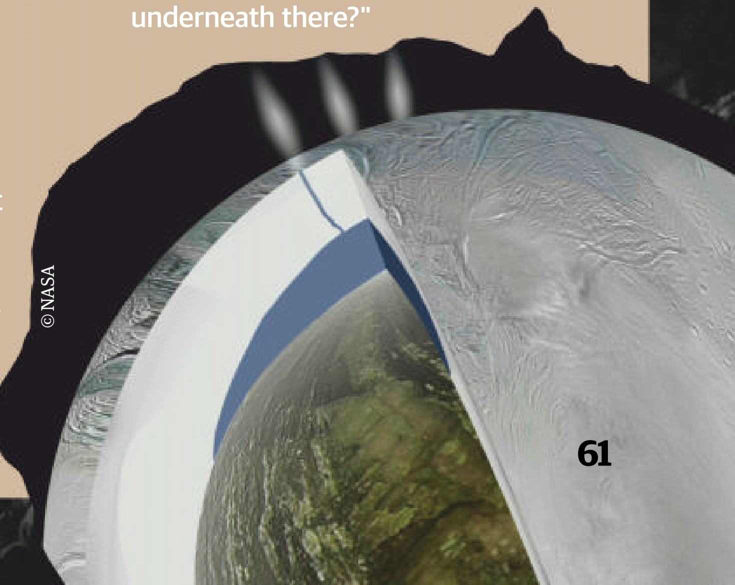
Titan

Earlier this year researchers studying rising and falling lakes on Saturn's moon Titan presented evidence that some liquid may be seeping into the rocks themselves. The result would be a karst landscape similar to those we find on Earth, with caves, springs, aquifers and sinkholes. "We've been talking about possible missions with robotic explorers that might crawl down into lava tubes and caves," said Rosaly Lopes, a planetary scientist at NASA JPL, talking to **space.com**. "Could we in the future send one of these to sort of crawl down into this terrain and into caves and find out what's underneath there?"

Enceladus

Salt-water caverns could be found beneath the surface of this small Saturnian moon. These are thought to exist between the moon's icy surface and the subsurface oceans which were discovered by Cassini. John Spencer at the Southwest Research Institute in Boulder, Colorado has suspected these caverns would be filled with water vapour at higher pressure.



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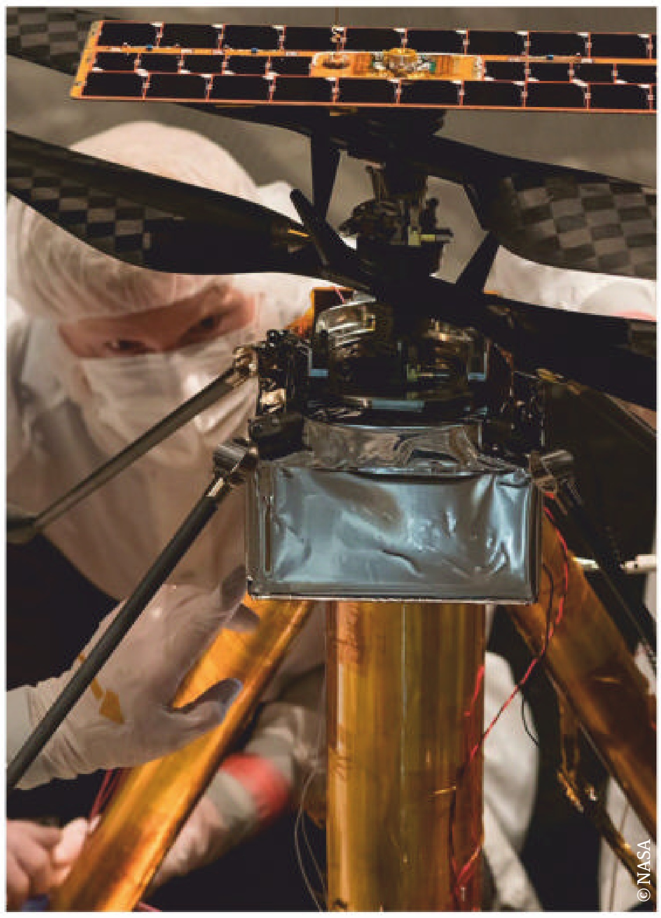
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missions, suggesting they focus on simply proving a target tube extends beyond the observable collapse pit. "As you go deeper in subsequent missions you can set up infrastructure… lines of communication, lines for power and a tunnelling system to let astronauts in and out."

It's at this point that human habitation becomes a real possibility. But before we start picking out curtains, we need to remember the three most important factors in real estate - location, location and location. And one key question in the subsurface is how deep do you go? From a radiation shielding perspective, not that far apparently.

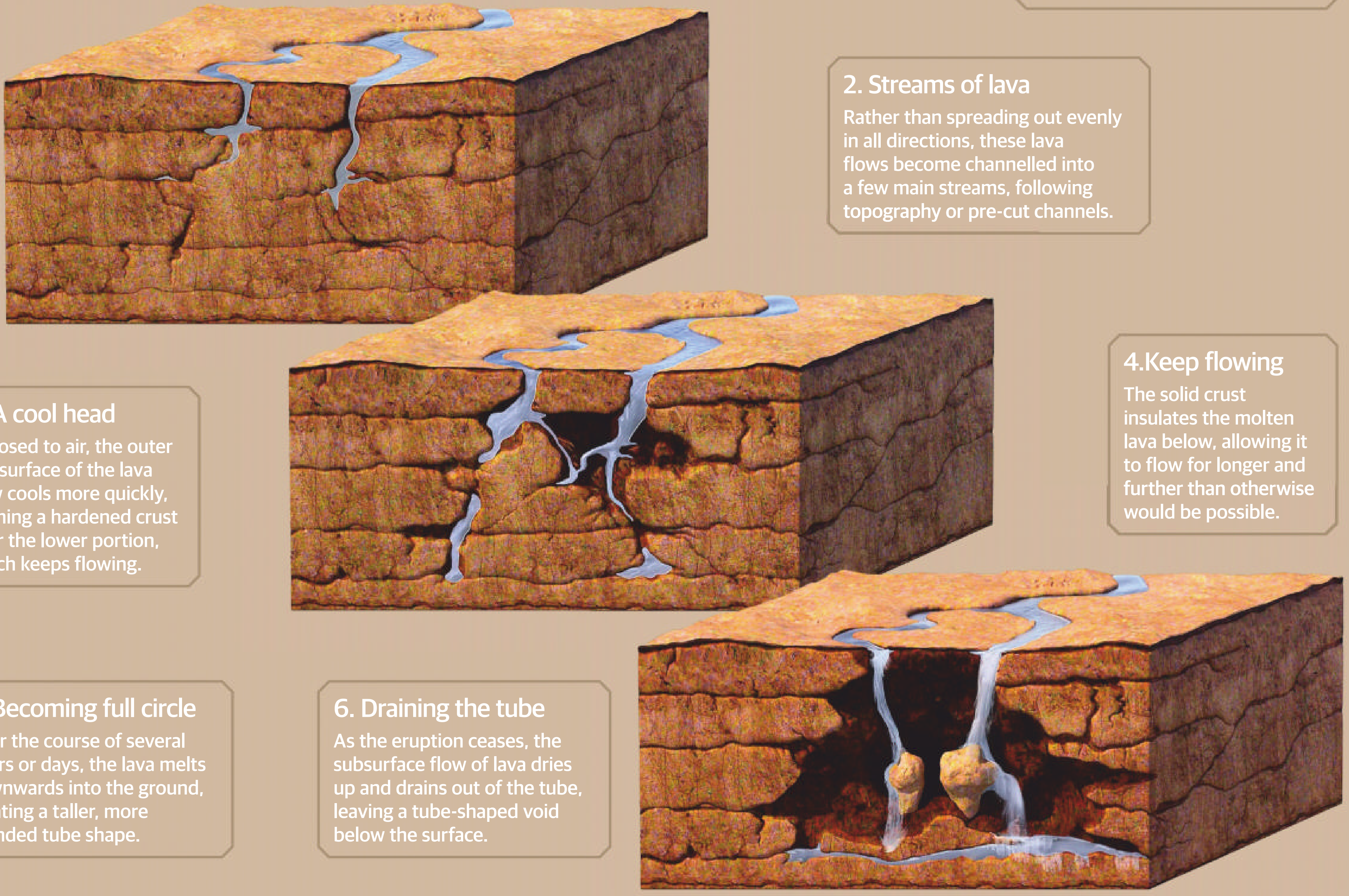
"I heard a lot of estimates, everything from a metre to two or three," says von Ehrenfried. "Some people even suggested you could get away with less than that." That doesn't mean we won't be venturing deeper for resource mining. This may also influence the choice of target cave on a planetary-wide scale. For example, the water under the Moon's south pole makes a strong case for setting up camp there. "Once you have water ice, the engineers want the water to break it up into oxygen and hydrogen, and make fuel and potable water," says von Ehrenfried.

Temperature is also a factor. It varies much less day to night the deeper you go into a cave, though this must be balanced with increasing costs of laying power and communications infrastructure. Whichever site is chosen, the next question is what structures will we, or our robotic forerunners, build? The first cave Martians will likely enjoy the latest in science and communications technology, though these will need to be specially adapted to this

> "For the people who live in caves, they perceive the cave not as scary, but as cosy. A safe place" **Martin Gasser**

Case study: how caves formed on Mars

All the evidence suggests Hawaiian-style lava tube networks are common under the Red Planet



1. Near a volcano
Lava tubes tend to form in the vicinity of shield volcanoes like those of Hawaii, which produce fast-moving, basaltic lava flows.

2. Streams of lava
Rather than spreading out evenly in all directions, these lava flows become channelled into a few main streams, following topography or pre-cut channels.

3. A cool head
Exposed to air, the outer top surface of the lava flow cools more quickly, forming a hardened crust over the lower portion, which keeps flowing.

4.Keep flowing
The solid crust insulates the molten lava below, allowing it to flow for longer and further than otherwise would be possible.

5. Becoming full circle
Over the course of several hours or days, the lava melts downwards into the ground, creating a taller, more rounded tube shape.

6. Draining the tube
As the eruption ceases, the subsurface flow of lava dries up and drains out of the tube, leaving a tube-shaped void below the surface.

© Nicholas Forder

unique underground setting.

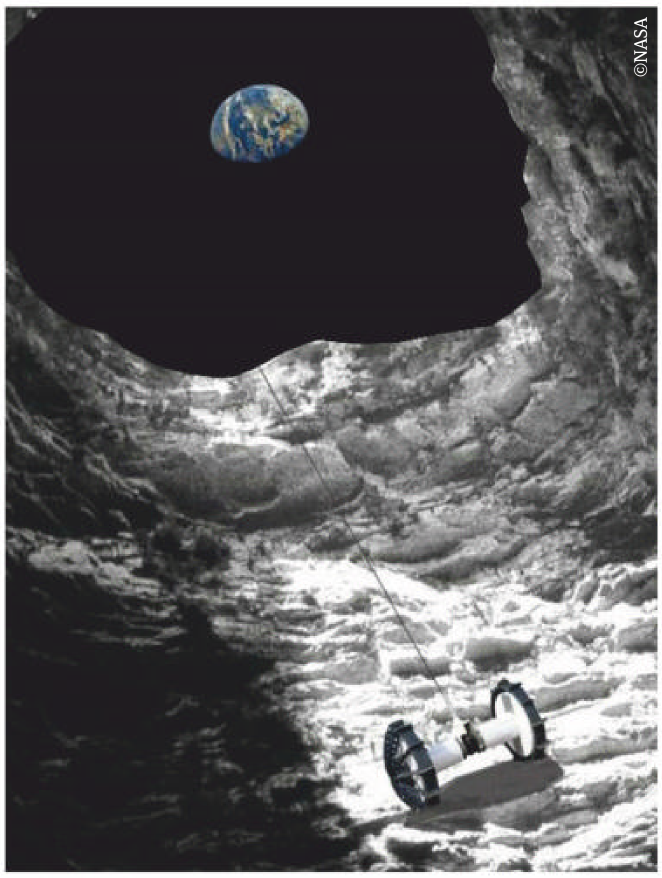
Gasser has learned from personal experience that many electromagnetic communication technologies do not work well in caves due to the magnetism of the surrounding rock. "You may need to leave a breadcrumb trail of lots of little routers," he suggests. To save on transportation some designers have taken inspiration from Bigelow Aerospace's inflatable habitation module currently being tested while attached to the International Space Station. However, such expandable material will have to be tough, warns Gasser: "There are only pointy surfaces in a cave. Any kind of habitation will have to be resistant to hard and sharp rock edges."

Though extended periods on the surface of the Moon or Mars can be harmful, Gasser can attest to the mental health struggles that come with natural light deprivation. As a result, however comfortable the home you build underground, he believes it vital to allow residents some access to the surface.

So what next? Both von Ehrenfried and Thanga believe space agency priorities for subsurface habitation seem focused on the Moon initially, particularly since the detection of polar water. Thanga, for his part, is working with planetary scientists to propose low-cost missions to get SPEER off and then under the ground. In the meantime he continues to run tests, including building mockup caves in his lab. "We're using paper mache to make the lab look like a lava tube. It's almost parallel to what the folks at Hollywood would do."

Wherever you look, momentum is building. In their roles at 4th Planet Logistics Gasser and Feucht are in talks with the ESA around rover testing to plan for future trips under the Moon, while at the start of the year a company called Astroland even began offering underground expeditions in Spain that simulate a human colony on Mars.

How realistic these tourists' experience will be to that of the first humans living under a new world is debatable. However, both ventures may in their own way change thinking around subsurface living. "For many people it's a scary thought to go into a cave and just be surrounded by rock," says Gasser. "However, for the people who live in caves, they perceive the cave not as scary, but as cosy. A safe place."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Bottom left (clockwise): This summer NASA's Mars 2020 rover was fitted with a small helicopter to explore subterranean channels

Abseiling rovers like Axel can explore caves with a tethering cable that can also relay power and communications to the surface

NASA astrobiology mission BRAILLE is using a four-wheeled NASA test rover to explore Earth's caves as practice for exploring caves on Mars and the Moon

©NASA

What these caves could be used for

There are many reasons to investigate these off-world caves

Natural shelter

The subsurface network of lava tubes on Mars and the Moon can save mission time erecting shelters on the surface while also protecting astronauts from harmful radiation and micrometeorites constantly raining down.

Finding life

If life once existed on Mars, the evidence is likely to be underground. Periodic spikes in methane have been measured within the Martian atmosphere, which some astrobiologists have put forward as possible evidence of cave-dwelling, methane-producing microorganisms.

Understand the history of Mars

Current exploration of Martian geology is limited to surface layers and minor depths from rover drilling. Caves provide an opportunity to travel back millions or billions of years by reading the story preserved in lava tube walls.

Mining

Initial interest in the Moon's subsurface was in anticipation of future lunar mining. The discovery of lava tube networks might make a stronger economic case by showing a lot of excavation has already been done.

Growing food

On Earth, volcanic soils provide some of the most nutrient-rich soils available for farming. Perhaps similarly mineral-rich lunar regolith could be converted into soils to grow food that will sustain inhabitants of the first lunar bases?

MYSTERIES OF THE UNIVERSE

WHY IS OUR GALAXY BLOWING BUBBLES?

Has our Milky Way been forever spitting out radiation from its centre? We could have finally discovered what's causing it

Reported by David Crookes

For a decade astronomers have been looking to the sky and sighing with frustration as the Milky Way spews giant plumes of high-energy particles with no firm explanation as to what is behind them. They were first discovered in 2010 using NASA's Fermi Gamma-ray Space Telescope, but despite numerous studies over subsequent years these bubbles – which given current astronomical theory shouldn't exist at all – continue to be a mystery.

"What we see are two gamma-ray-emitting bubbles that extend 25,000 light years north and south of the galactic centre," said Professor Douglas Finkbeiner, an astronomer at the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, after recognising the celestial feature. Named Fermi Bubbles, they were seen to extend 50,000 light years in total above and below the plane of the galaxy.

The discovery was, colleague Meng Su would later admit in a roundtable discussion hosted by the Kavli Foundation, "quite a big shock", even though evidence of other bubble-like structures exist in the universe. "Finding these bubbles in the Milky Way wasn't anticipated by any theories," he continued. The reason? The supermassive black hole in the

© Nicholas Forder

centre of the Milky Way is far less massive than in the galaxies where other bubbles were observed. A small galaxy shouldn't be capable of causing this.

And yet the Fermi Bubbles are all too evident, having been initially revealed by processing data taken by Fermi's Large Area Telescope. It's an advanced piece of imaging kit capable of detecting individual high-energy gamma rays in the energy range between 20 MeV and 300 GeV. For gamma rays to be emitted in this range, the particles have to move very close to the speed of light - Fermi is the most sensitive and highest resolution gamma-ray detector ever put into orbit.

Launched in 2008, it needed such a precise instrument because the sky is obscured by a fog of gamma rays - in part due to the particles interacting with the Milky Way's light and interstellar gas. Fortunately the Fermi team were able to estimate the gamma-ray fog and subtract the findings from the Large Area Telescope data.

This showed the bubbles were more energetic than the fog and that they had well-defined edges, with a statement put out by NASA at the time adding: "The structure's shape and emissions suggest it was formed as a result of a large and relatively rapid energy release." But what is causing extremely energetic electrons within the bubble to interact with lower energy light to create the gamma rays, and what's the source of the electrons?

The fact that the Fermi Bubbles extend outwards at an equal distance north and south from the central regions of our galaxy has not gone unnoticed. This almost-perfect hourglass shape of sorts suggests they are linked in some way to the supermassive black hole at the centre of the Milky Way called Sagittarius A*, which is 4 million-times as massive as the Sun. Astronomers have likened it to a kind of giant burp, which is odd given Sagittarius A* is mostly quiet.

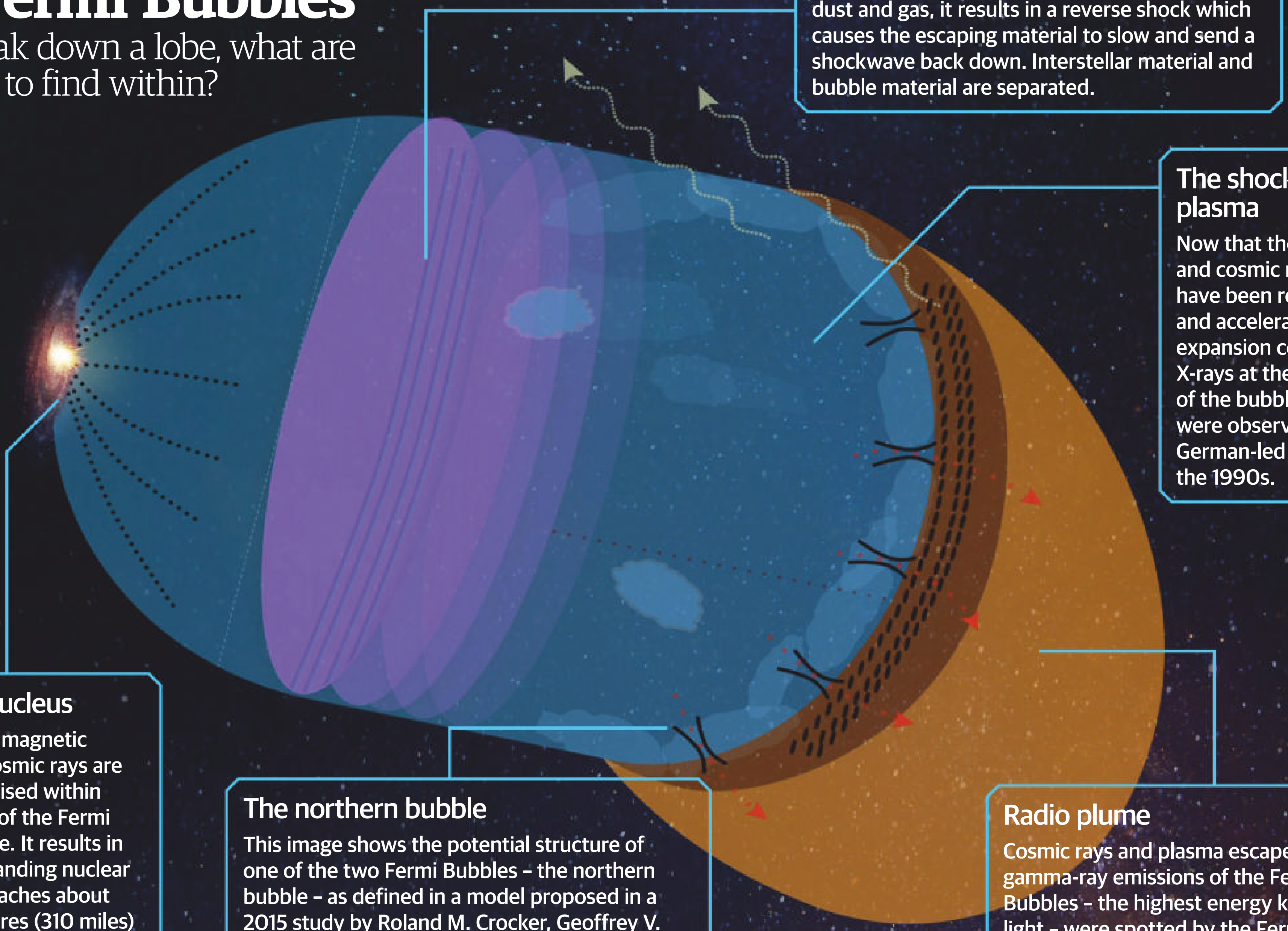
Could it be that this supermassive black hole has been much more active in the past? It is certainly possible that Sagittarius A* has gobbled up huge amounts of gas, dust and stars and produced large outflows of plasma in the guise of giant jets of particles, otherwise how else has it grown to 4 million solar masses? Should high-energy electrons have collided with photons to create gamma rays millions of years ago, that would go a long way to explaining the violent launch of energised gas that we've only seen relatively recently.

Thankfully, more studies have shed further light on the mystery, picking up the structure in X-rays and radio waves. One study in 2015 presented data that had been sourced by the Hubble Space Telescope, with Dr Andrew Fox of the Space Telescope Science Institute in Baltimore observing ultraviolet light emitted by a bright, distant quasar situated behind the northern Fermi Bubble. By

Right: The magenta sections of both Fermi Bubble lobes show gamma-ray emissions, with the blue highlighting the X-ray emissions. The lobes are north and south of the Milky Way's plane and extend out more than 50,000 light years in total

The formation of the Fermi Bubbles

If we break down a lobe, what are we likely to find within?



A reverse shock

As the jets collide with a surrounding layer of dust and gas, it results in a reverse shock which causes the escaping material to slow and send a shockwave back down. Interstellar material and bubble material are separated.

The shocked plasma

Now that the plasma and cosmic rays have been reheated and accelerated, expansion continues. X-rays at the edge of the bubbles were observed by a German-led mission in the 1990s.

Galactic nucleus

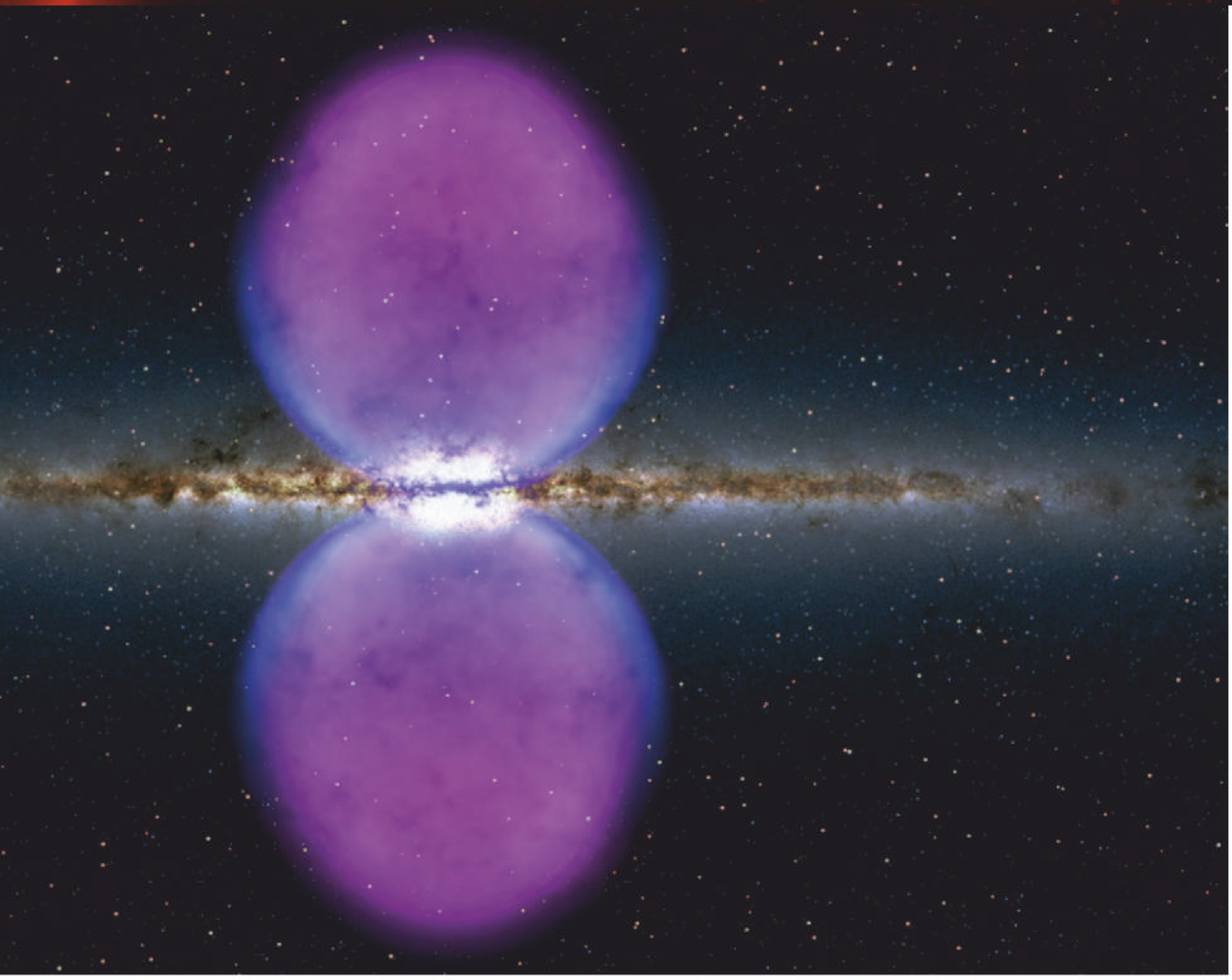
Hot plasma, magnetic fields and cosmic rays are highly energised within the nucleus of the Fermi Bubble's lobe. It results in a freely expanding nuclear wind that reaches about 500 kilometres (310 miles) per second.

The northern bubble

This image shows the potential structure of one of the two Fermi Bubbles - the northern bubble - as defined in a model proposed in a 2015 study by Roland M. Crocker, Geoffrey V. Bicknell, Andrew M. Taylor and Ettore Carretti.

Radio plume

Cosmic rays and plasma escape. The gamma-ray emissions of the Fermi Bubbles - the highest energy kind of light - were spotted by the Fermi teams, and they are produced by cosmic rays.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> "What we see are two gamma-ray-emitting bubbles that extend 25,000 light years north and south of the galactic centre" **Prof Douglas Finkbeiner**

pairing Hubble's Cosmic Origins Spectrograph with quasar PDS 456 as its light - generated by fast-moving particles - passed through the bubble's base, Fox and his team could at least get an idea of the bubbles' composition and speed.

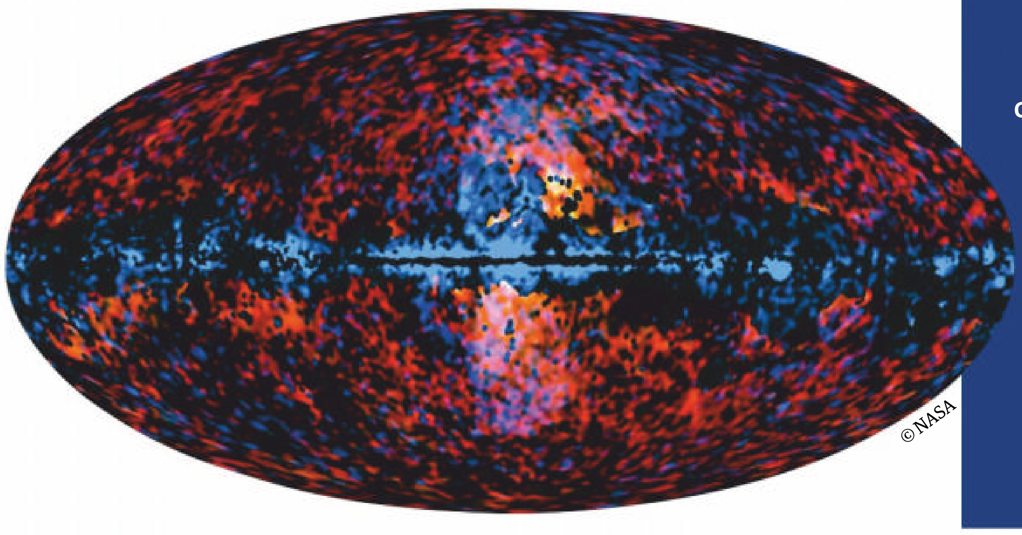
"Looking at a background quasar allowed us to study the Fermi Bubbles from a whole new perspective, using ultraviolet radiation," Fox tells us. "By observing this UV radiation with the Cosmic Origins Spectrograph on board the Hubble Space Telescope, we detected the spectral 'fingerprints' of cool clouds embedded in the Fermi Bubbles.

"These fingerprints take the form of absorption lines at specific wavelengths of radiation. This allowed us to measure the motion and chemical composition of gas moving in the Fermi Bubbles, which had not been done before. These are important clues for understanding the origin of the bubbles and the role they play in galaxy evolution."

The work found that the structures were extending 30,000 light years above and below the galactic plane at a speed of 3.2 million kilometres (2 million miles) per hour - moving towards the Sun on the northern lobe's near side and away on the southern's. Astronomers were also able to ascertain that whatever was causing the Fermi Bubbles happened any time between 2.5 and 4 million years ago and that there was an abundance of silicon, carbon and aluminium. This is significant because those heavy elements are produced inside stars, and therefore represent the ancient remnants of star formation. A second possible origin for the Fermi Bubbles is a firestorm of star birth at the centre of the Milky Way. There's a chance the stars around the black hole went supernova at the same time.

The scientists were able to get an idea of temperature, showing the gas reaching 9,700 degrees Celsius (17,500 degrees Fahrenheit), which Fox said could be interstellar gas from the Milky Way swept up in the hot outflow. He also theorised that the outflows occurred episodically. "It looks like the outflows are a hiccup," Fox said in a statement at the time. "There may have been repeated ejections of material that have blown up, and we're catching the latest one."

Below: An all-sky image picked up by the European Space Agency's Planck mission at microwave frequencies superimposed over the high-energy sky shows the Fermi Bubbles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Cosmic rays by numbers

1912
The year cosmic rays were discovered

2
Types of cosmic ray: galactic and extragalactic

90%
of cosmic rays' nuclei are hydrogen

9%
of cosmic rays' nuclei are helium

1%
of cosmic rays' nuclei are other heavier elements

10 GeV
The highest energy of a cosmic ray, which corresponds to 99.6 per cent the speed of light

4.1
The amount of gold, in centimetres, that charged cosmic rays were found to penetrate

The theories

There are some competing theories about the source of the Fermi Bubbles

Fermi Bubbles are associated with Sagittarius A*

The most likely explanation for the Fermi Bubbles appears to be a rapid energetic event at the centre of the Milky Way which took place less than 10 million years ago. This theory is based on gamma ray, X-ray and radio studies, with further research suggesting that they were caused by the supermassive black hole Sagittarius A* creating the bubbles over a few million years.

The bubbles were created by gradual star formation

This theory argues that the Fermi Bubbles were created by more gradual star formation from stars around the galactic centre. This would have taken place over a period of a few hundred million to a billion years ago, but Professor Rongmon Bordoloi says the findings of his study which estimated the Fermi Bubbles' age from their velocity information rules this out.

A star was ripped to pieces as it got close

Could it be that a star got very close to the supermassive black hole Sagittarius A*, causing it to be torn into tiny pieces that released a huge amount of gravitational energy which manifested as the Fermi Bubbles? There is still a possibility that this happened, and that is why studies are continuing in this field of astronomy.

A couple of years later Fox returned with a second study, led by Dr Rongmon Bordoloi of the Massachusetts Institute of Technology. This one found that Sagittarius A* last chomped down on a large clump of infalling gas about 6 million years ago, and it suggested that a massive bubble of gas was then emitted, creating the Fermi Bubbles. "Researchers agree that the Fermi Bubbles were created by an energetic event at the galactic centre," Fox tells us. "The main question is whether that event was related to the central supermassive black hole or to star formation near the galactic centre."

Again the observations were made by the Hubble Space Telescope's Cosmic Origins Spectrograph, drawing upon the ultraviolet light from 47 distant quasars. It found the edge of the northern bubble to be 23,000 light years above the galactic plane, and it estimated the mass of the gas in both bubbles to be equivalent to 2 million Suns at the very least.

"Our approach was a unique and orthogonal experiment to study the kinematics of the diffuse atomic gas entrained in the Fermi Bubbles," Bordoloi tells us. "Until that period there had been a lot of work on the Fermi Bubbles, mainly mapping out the X-ray and gamma-ray properties of the gas.

"None of these studies focused on the velocity of the gas itself, so we decided to study how fast the atomic gas entrained in the Fermi Bubbles is moving by measuring ultraviolet light from distant quasars that lie behind the Fermi Bubbles using the Hubble Space Telescope. That light had information imprinted on it as it travelled through the lobe about the velocity, composition and temperature of the expanding gas inside the bubble."

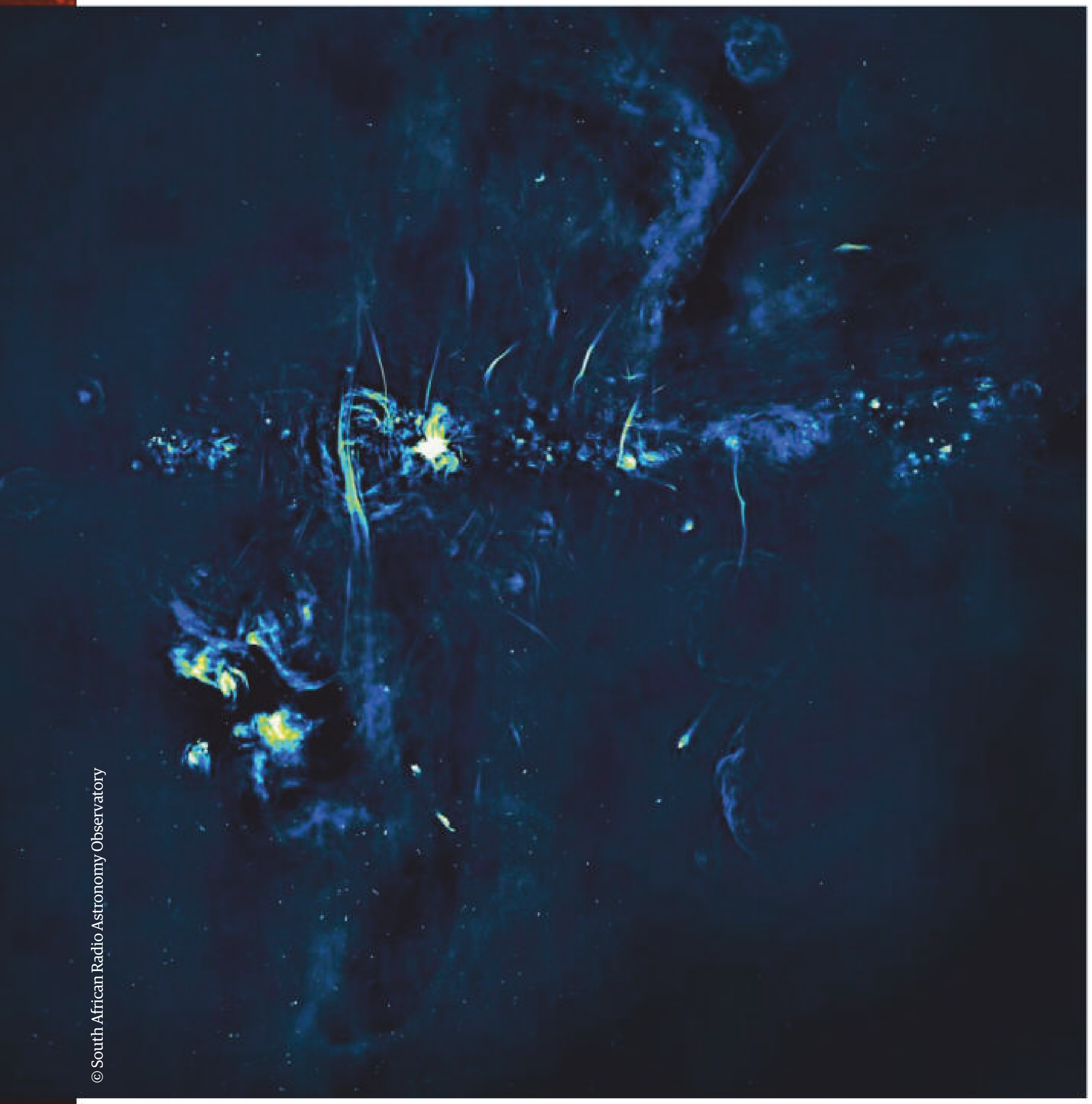
Fast forward to 2019 and the European Space Agency (ESA) reported a breakthrough discovery. Its X-Ray Multi-Mirror Mission, also known as XMM-Newton, had been scanning the skies for interstellar X-ray sources, performing narrow- and broad-range spectroscopy and simultaneously imaging objects in X-ray and optical wavelengths between 2016 and 2018. As it was making an extensive X-ray map of the Milky Way's core, it picked up on two channels of super-heated, X-ray-emitting gas streaming from Sagittarius A*. For the first time there was a link between the Fermi Bubbles and the surroundings of the black hole.

Just like the Fermi Bubbles, the channels were to the north and south of the galactic plane, and they extended for hundreds of light years. According to the ESA they transport energy and mass from the heart of the Milky Way to the base of the bubbles, allowing them to be fuelled by fresh material. The space agency drew two immediate theories from this: that supermassive black holes can be quiet and yet burp energetic outflows of material or, in the case of Sagittarius A*, the activity was from a time when it was much louder than it is today.

Even so, the mystery remains in situ, and there is no widely accepted conclusion because more evidence is needed. Attempts to firm up hypothesises have not always come to fruition either. It's known, for instance, that cosmic rays - those high-energy protons and atomic nuclei which are thought to be producing the gamma rays - can interact with one another and produce dark particles called neutrinos, which barely interact with anything else of normal matter. These have been detected in the rough direction of the Fermi Bubbles, but is the evidence merely circumstantial?

The IceCube Observatory at the Amundsen-Scott South Pole Station in Antarctica has detected ten neutrinos from the direction of the Fermi Bubbles. It has done so by making use of a cubic-kilometre particle detector made of ice and buried at a depth of 2,500 metres (8,202 feet). When a neutrino travels from its source to Earth and passes through the ice, it interacts with a water molecule. This produces an electrically charged secondary particle that emits detectable Cherenkov radiation since it travels through the ice faster than light does. What does it mean? Well, if neutrinos are being formed within the Fermi Bubbles, then subatomic interactions are likely to be taking place.

There is a chance that the neutrinos are being formed somewhere else, beyond the Fermi Bubbles, but supposing they are originating within the bubbles, scientists have sought to explore whether there is a set of interactions producing both gamma rays and the neutrinos that have been detected. To do so researchers have looked through seven years



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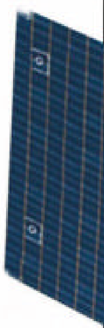
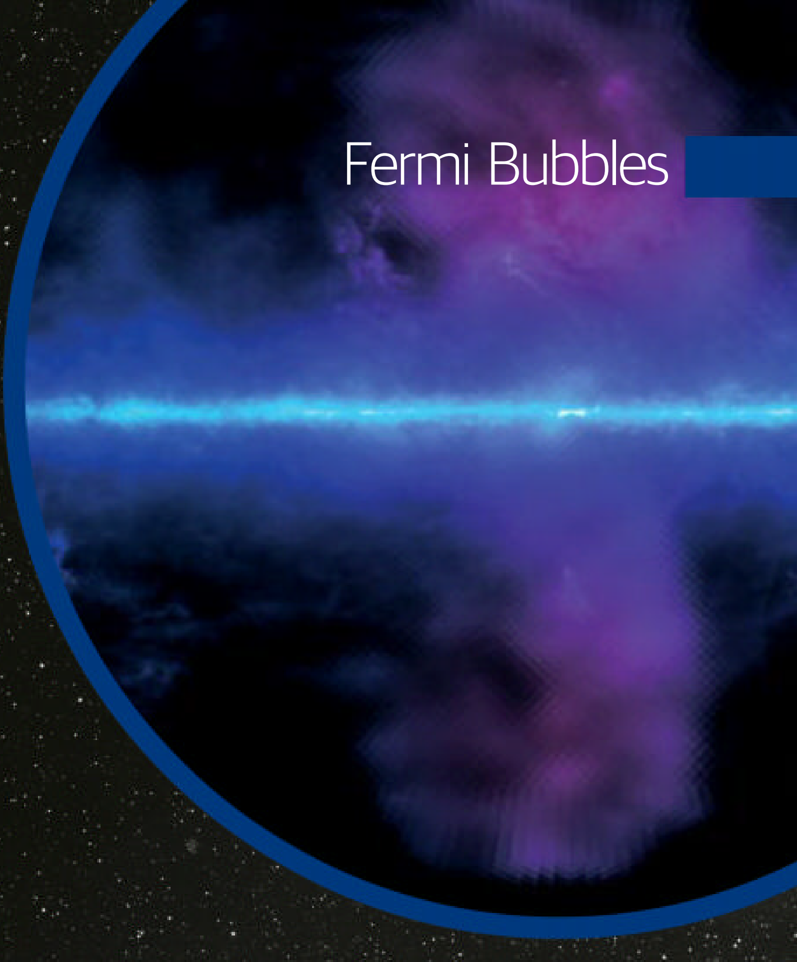
Left: Recently a radio telescope array called MeerKAT detected bubble-like radiowave structures next to the Fermi Bubbles - could they be fuelling the bubbles' inflation?



Mission profile: Fermi Gamma-ray Space Telescope

How astronomers were first able to discover the lobes of the Fermi Bubbles



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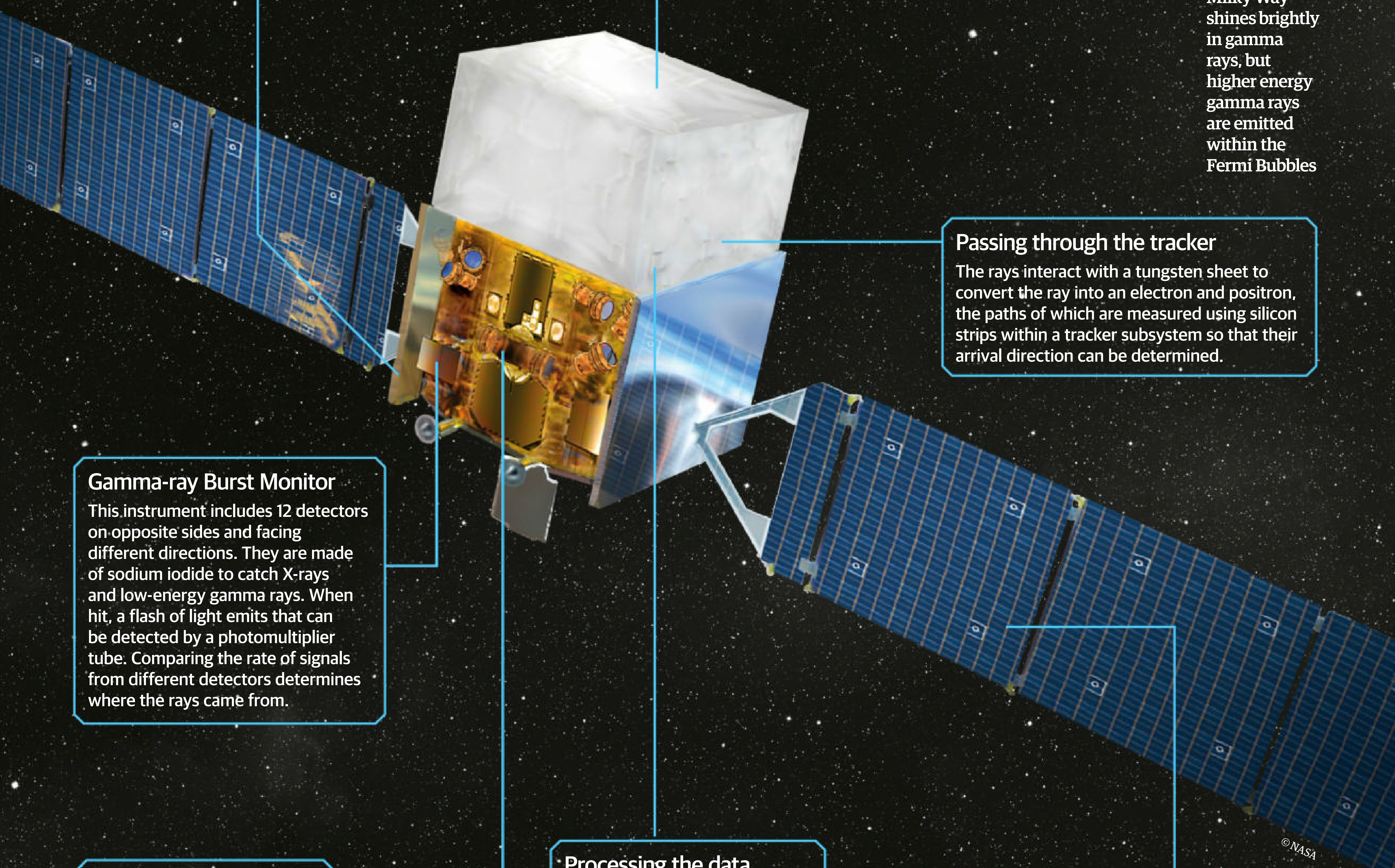
Above: The blue-coloured plane of the Milky Way shines brightly in gamma rays, but higher energy gamma rays are emitted within the Fermi Bubbles



Collecting gamma-ray data

The Fermi Gamma-ray Space Telescope which launched on 11 June 2008 observes light in the photon energy of between 8,000 and 300 billion electronvolts. It collected the data which astronomers Douglas Finkbeiner, Tracy Slatyer and Meng Su used during their discovery of the Fermi Bubbles.

The Large Area Telescope

The Large Area Telescope is comprised of four subsystems, and it works to detect and isolate gamma rays. There are 16 towers of particle detectors. First the gamma rays have to pass through the anticoincidence detector.

Passing through the tracker

The rays interact with a tungsten sheet to convert the ray into an electron and positron, the paths of which are measured using silicon strips within a tracker subsystem so that their arrival direction can be determined.

Gamma-ray Burst Monitor

This instrument includes 12 detectors on opposite sides and facing different directions. They are made of sodium iodide to catch X-rays and low-energy gamma rays. When hit, a flash of light emits that can be detected by a photomultiplier tube. Comparing the rate of signals from different detectors determines where the rays came from.

High-energy detectors

The Gamma-ray Burst Monitor also has two further detectors that are made from bismuth germanate, which catches high-energy gamma rays. Their positioning means they provide close to total full-sky coverage.

Processing the data

The electron and positron are then passed into the calorimeter to measure their energies, with the combined information then processed by the Data Acquisition System. This works out which signals are real gamma rays and sends the data to scientists to work with.

Powering the instruments

Solar panels measuring 15 metres (49 feet) from tip to tip are on either side of the instruments. There are also cooling radiators for the Large Area Telescope.

© NASA

“On balance, there is currently more evidence in favour of the supermassive black hole origin” **Dr Andrew Fox**

of data, studied proposed models and even made use of information gleaned from the High Altitude Water Cherenkov Experiment detector, situated on the flanks of the Sierra Negra volcano in Mexico.

Perhaps high-energy protons inside the bubbles are colliding and producing unstable subatomic particles called pions which decay into a pair of gamma rays. Or maybe, the scientists have explored, high-energy electrons are interacting with the cosmic microwave background, causing protons to become gamma rays. Particles may even be driven to high velocities by shockwaves on the Bubbles' outer edges using magnetic fields, which causes them to emit cosmic rays. Unfortunately no explanation is able to smoothly slot into the dataset, and there are anomalies aplenty.

What's more, the Fermi Bubbles are not alone. In September 2019, Ian Heywood, an astronomer at the University of Oxford, discovered two giant radio bubbles close to Sagittarius A* that extend above and below the Milky Way for more than 1,400 light years. Again this suggests an extremely energetic explosion, perhaps caused by a burst in star formation or a burping out of consumed material, with astronomers believing the origin of the new discovery was caused by a small yet similar event to that behind the Fermi Bubbles. But what's the most likely explanation?

“On balance, there is currently more evidence in favour of the supermassive black hole origin,” affirms Fox. “In this picture, a gas cloud falls too close to the central supermassive black hole and gets torn apart, causing an energetic outburst that drives gas into the halo of the galaxy and creates the bubbles. This event, known as a Seyfert flare, happened several million years ago. Such a flare can explain the bubbles’ enormous energy, the possible existence of jets and the properties of gas clouds far out in the galactic halo that are ionised by the intense radiation from the flare.”

Right: The Fermi Gamma-ray Space Telescope with its solar arrays folded while it was being prepared on Earth

© NASA

Q&A

Rongmon Bordoloi, Assistant Professor of Physics at North Carolina State University

What would happen if the Fermi Bubbles were close to Earth?

The bubbles are manifested perpendicular to the plane of the Milky Way, so if we were closer to the bubbles, we would still not be inside the bubbles. But since we would be close to the bubbles, their angular size in the sky would be bigger than what it is now. They would also appear brighter in different wavelengths than now as we would be closer to them. Otherwise things would not change too much.

What would happen if we sent a spacecraft towards them?

The bubbles are comprised of hot relativistic plasma, with temperatures exceeding 100,000 to 1,000,000 degrees Kelvin. However, this plasma is very diffuse, so even if we send a spacecraft towards them, the spacecraft would be fine. The only problem would be if you are close to the galactic centre, you might experience massive doses of radiation coming from cosmic rays originating from the galactic centre. An astronaut might have a higher risk of cancer, but the spacecraft itself should be fine.

If you managed to fall into Sag A*, would the bubbles throw you out?

If you fall into SagA*, first you will be stretched and become elongated like spaghetti, owing to the strong gravity. After that, as you keep falling inward you will be torn apart into your constituent atoms. Most of these atoms will disappear into the supermassive black hole. Only about one per cent of these atoms may be thrown back out and be in the bubbles.

What would happen if they extended further, and how far could they go?

If the bubbles extended further, they would expand more and their shape would become more and more spherical at the top. The density of material would also reduce as they expand, and if they keep going at some point they would hit the circumgalactic medium of the Milky Way. It is hard to predict how far they would go, but they will halt when the pressure from the circumgalactic medium balances the pressure from the bubble expanding them. We would stop seeing them quite early on as density of material would be so low that the surface brightness of the bubbles would be too low to be detected by any current instrument.

What would happen if we could harness the bubbles' energy?

The bubbles have an enormous amount of energy, equivalent to trillions of supernovae explosions. If we could harness even a tiny fraction of that energy, we would never need any other energy source ever.

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ASK Space

Our experts answer your questions

At their core, gas giants and ice giants are the same

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PLANETS

What's the difference between a gas giant and an ice giant?

At their hearts, gas giant and ice giant planets are not so different. Really, a gas giant is just an ice giant with a lot more gas! The way we think that giant planets form is that an initial ball of ice and rock – a protoplanet – forms within the solar nebula, the disc of gas – mostly hydrogen and helium – and solids around a young sun. Once the protoplanet reaches about ten-times the mass of the Earth, it starts to have enough gravity to accrete solar nebula gas down on top of it. This accretion makes the protoplanet more massive, with an even better ability to grab even more gas. This gas accretion process can almost reach a runaway, with more and more gas piling on top.

The initial protoplanet is therefore the 'seed' for planetary formation, and that part becomes the planet's core. Uranus and Neptune, our ice giants, only accreted a few Earth masses of gas, while Saturn accreted several dozens of Earth masses and Jupiter about 300.

One final thing to remember about all these planets is that their icy-rocky cores are under very high pressures and temperatures, so the 'ice' isn't actually a solid at all. It is a deep, fluid, ionic mixture of water, ammonia, and methane – that is most of the mass of Uranus and Neptune. And the hydrogen-helium 'gas' in Jupiter and Saturn is under such high pressure that it has a density similar to a glass of water.

Jonathan Fortney is a professor in the department of astronomy and astrophysics at the University of California, Santa Cruz

COSMOLOGY

How do we know the universe's age?

After Edwin Hubble discovered the universe's expansion, scientists deduced that if the universe is currently getting larger, it must have once been much smaller. Constraining the age of the universe involves understanding the expansion history of the universe; the universe's expansion rate is ultimately determined by its contents.

Over the past several decades, scientists began to measure the contents of the universe, thus constraining its expansion history. This was achieved using various astronomical observations, especially measurements of the universe's first light, the cosmic microwave background. Given measurements of the universe's expansion rate today, cosmologists can calculate the amount of time the universe has expanded, giving the figure for the age of the universe as 13.8 billion years.

Zhili Xu is a researcher in the department of physics and astronomy at the University of Pennsylvania

The expansion of the universe reveals its age

Andromeda is gravitationally bound to the Milky Way

ASTROPHYSICS

What will happen to the Milky Way when it collides with the Andromeda Galaxy?

The Milky Way and Andromeda galaxies are hurtling towards each other at 100 kilometres per second (220,000 miles per hour). Presently they are roughly two million light years apart, and it will be 5 billion years until they are in close proximity.

The details of what happens then depends on the distance between the two galaxies at closest approach. Within present uncertainties there could be a direct hit or a wide swing-by. However, it is certain that their extended halos will merge. The tidal exchange of angular momentum will cause their cores to enter a spiral dance that tightens to union over the next few billion years.

Today these giant galaxies are spirals spinning in thin plans. Once they merge, after some exciting times of shock-induced star formation and feeding of gas into the black holes at their centres, the end result will be a red and dead elliptical galaxy; a star-pile with disorganised stellar orbits.

Richard Brent Tully is an astronomer at the Institute for Astronomy in Honolulu. He helped establish the 'Tully-Fisher Relation' of galaxies

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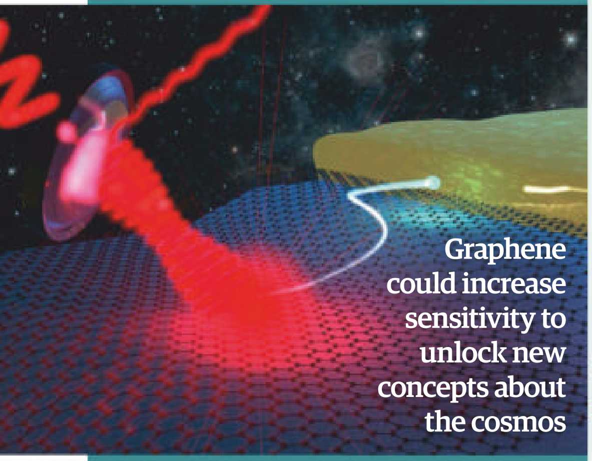
ASK Space

Our experts answer your questions



Graphene could increase sensitivity to unlock new concepts about the cosmos

©Hans He

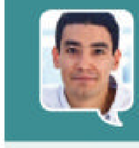
SPACE EXPLORATION

How can graphene improve telescopes?

Life as we know it depends on water, carbon and oxygen. But when, where and how are these formed, and how did they get to Earth? Astrophysicists seek to unravel these sorts of enigmas by looking at space by carefully studying the information encoded in the different colours of the electromagnetic spectrum. Molecules like water and elements such as oxygen and carbon show strong signatures in the terahertz (THz) portion of the spectrum, making the THz range of the spectrum important for understanding the chemical composition of our universe.

Astronomers resort to so-called coherent THz detectors to study fingerprints of water, carbon, oxygen and many other species originating from the most remote locations in the universe. Up to now some of the intrinsic material properties of superconductors have made it challenging to simultaneously fulfil all the stringent requirements needed to build arrays of coherent THz detectors capable of imaging large portions of the THz universe.

In our recent work we have shown that engineered graphene has a great potential to add a new material paradigm for THz heterodyne detection.



Samuel Lara-Avila is an assistant professor at Chalmers University of Technology

ASTROPHYSICS

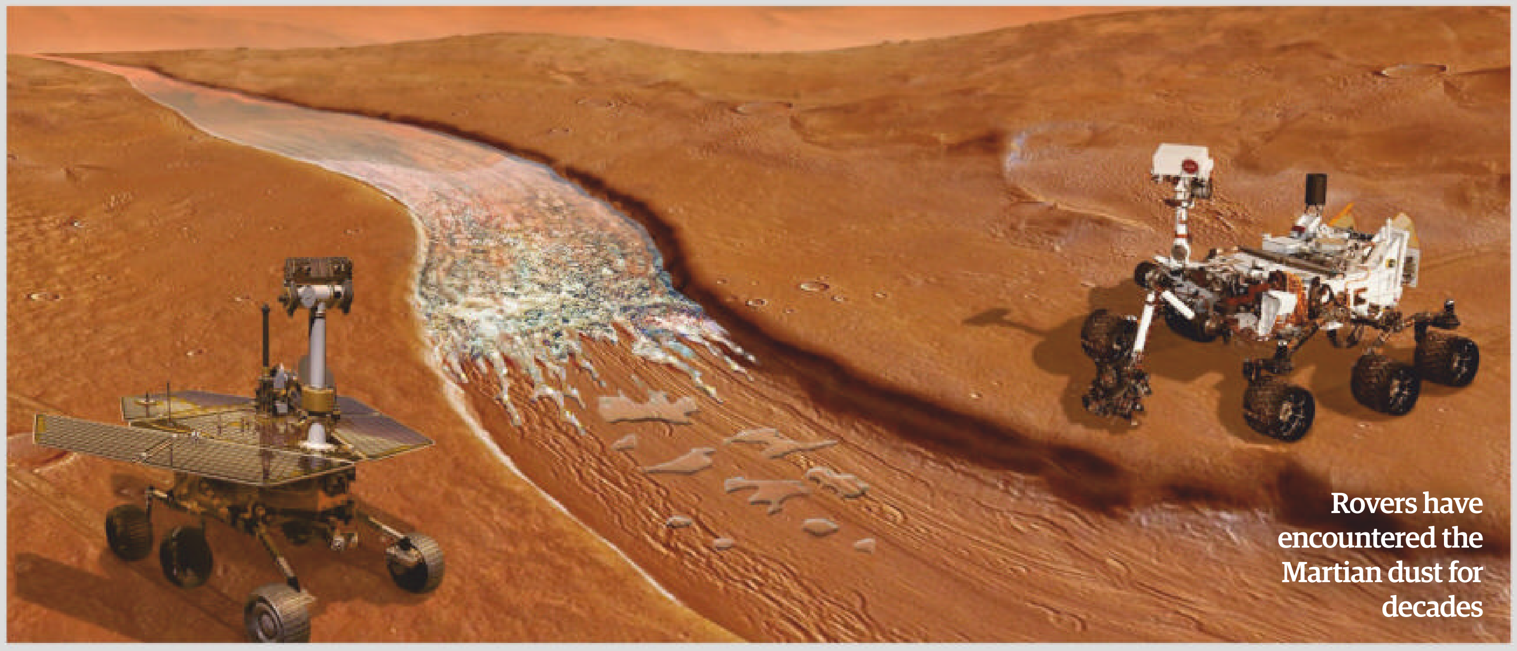
Why are there no purple or green stars?

Stars are dense and opaque spheres of gas in equilibrium, very close to the concept of black bodies defined by Max Planck in 1900. Quantum mechanics tells us that such bodies emit a continuum of light that peaks from red to blue as the temperature increases. The analogy would be from iron metallurgy or your oven, where the metal becomes bright red and then orange as it warms up. To have a blue metal you would need to heat it up to about 10,000 degrees Celsius (18,000 degrees Fahrenheit); this is different to a blue flame which is created by chemical reactions.

Therefore most stars are red, orange, yellow-white or blue. To obtain other colours it is necessary to suppress a large part of the emitted light, which can be done by absorbing atoms at the stellar photosphere. Given the wide variety of stars and surface compositions, there are indeed some examples of unusual colours. For instance, white dwarfs are former stars that have ended the nuclear conversion of helium to carbon. Some of them still have a large amount of carbon at their surface, which strongly absorbs the green in its molecular form. These objects are too faint to be seen with the naked eye, but would appear to have a whitish purple or pink colour because of the missing green light.

Usually it takes molecules to significantly absorb certain colours, which is why planets like Uranus can appear greenish due to methane absorbing the red light. However, this does not work at hotter temperatures, and we do not know of any green stars.

Pier-Emmanuel Tremblay is the associate professor of the Astronomy and Astrophysics group at the University of Warwick



Rovers have encountered the Martian dust for decades

©NASA/JPL-Caltech

PLANETS

What gives Mars its red appearance?

Mars is red because its surface and atmosphere contains abundant fine red dust. The dust has a brownish yellow chromaticity, but is reddish in colour. The dust is very fine-grained - microns in size - and some is almost always suspended in the atmosphere. It falls out of the atmosphere at a fairly constant rate and coats the surface.

There is a dust cycle on Mars that deposits substantial thicknesses of dust in certain parts of Mars. Tharsis, Elysium and Arabia Terra cover almost 20 per cent of the planet and have dust deposits that are at least metres thick. These areas are excluded as possible landing sites because the dust is not load bearing - NASA's Viking 1 footpad sank into dust and is completely covered.

Dust storms occur periodically on Mars when dust is injected into the atmosphere from surface dust loading centres. The dust can be so thick near these injection centres that it blocks out the Sun - this led to the end of NASA's Opportunity rover's mission - and cameras in orbit cannot see the surface. Mars is mostly made up of basalt, which forms from volcanism derived from partial melting of the mantle. The reddish colour of the dust is at least partly due to the presence of hematite and other oxidising weathering products of iron-bearing minerals, commonly referred to as rust.

Matt Golombek is one of NASA's Mars Exploration Program Landing Site scientists

Did you know?

Blue stars burn the hottest, with surface temperatures of above 12,000 Kelvin. They are also somewhat rare at only one in 3 million stars.

There are white, blue, yellow, orange and red stars, but where are the green and purple ones?

©Tobias Roetsch

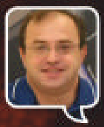
SOLAR SYSTEM

What Earth-like features does Titan have?

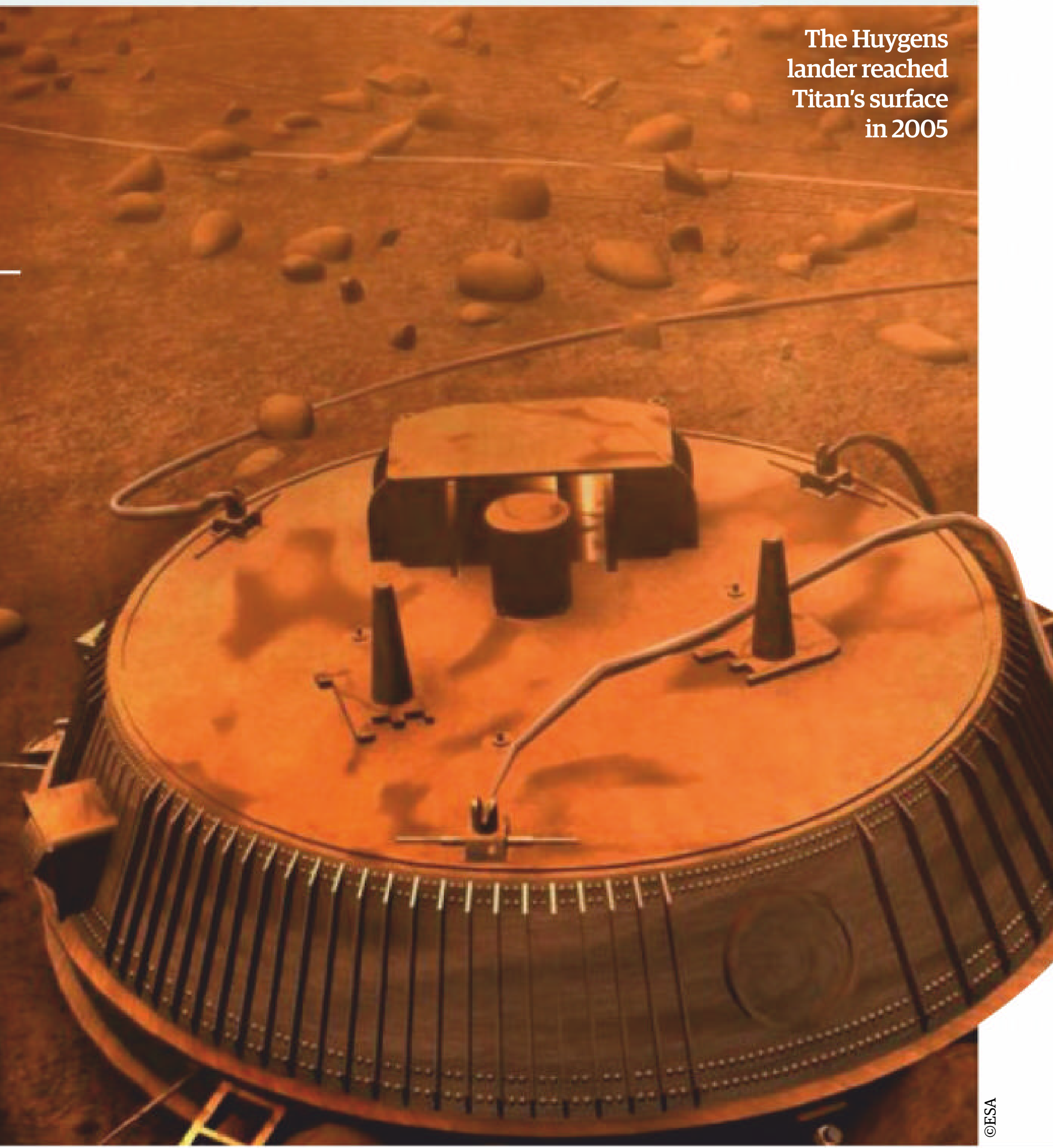
Titan presents unique geology for an icy satellite mainly due to the presence of a thick atmosphere. Previous to the Cassini-Huygens mission, Titan's surface was hidden by its hazy, orange atmosphere. The Cassini spacecraft and the Huygens probe unveiled an exotic but Earth-like world in many respects. Titan was found to possess vast dune fields, equatorial mountains and even lakes and seas at the poles. Titan is the only extraterrestrial body in our Solar System to possess standing bodies of liquid on its surface and is one of only three places in the Solar System, along with Earth and Mars, which we know of, to possess or have possessed an active hydrologic system, albeit with methane rather than water.

In a recent publication, my colleagues and I suggested that Titan's small lake basins with raised rims, some even surrounded by rampart features, share morphology and similar explosive origins analogous to lake basins formed as a result of terrestrial phreatic and phreatomagmatic explosions such as on Mars.

We suggested that these small lake basins with raised rims, such as Winnipeg Lacus and its surrounding lakes, are craters that are the result of explosive eruptions due to phase transitions of liquid molecular nitrogen in the shallow subsurface.



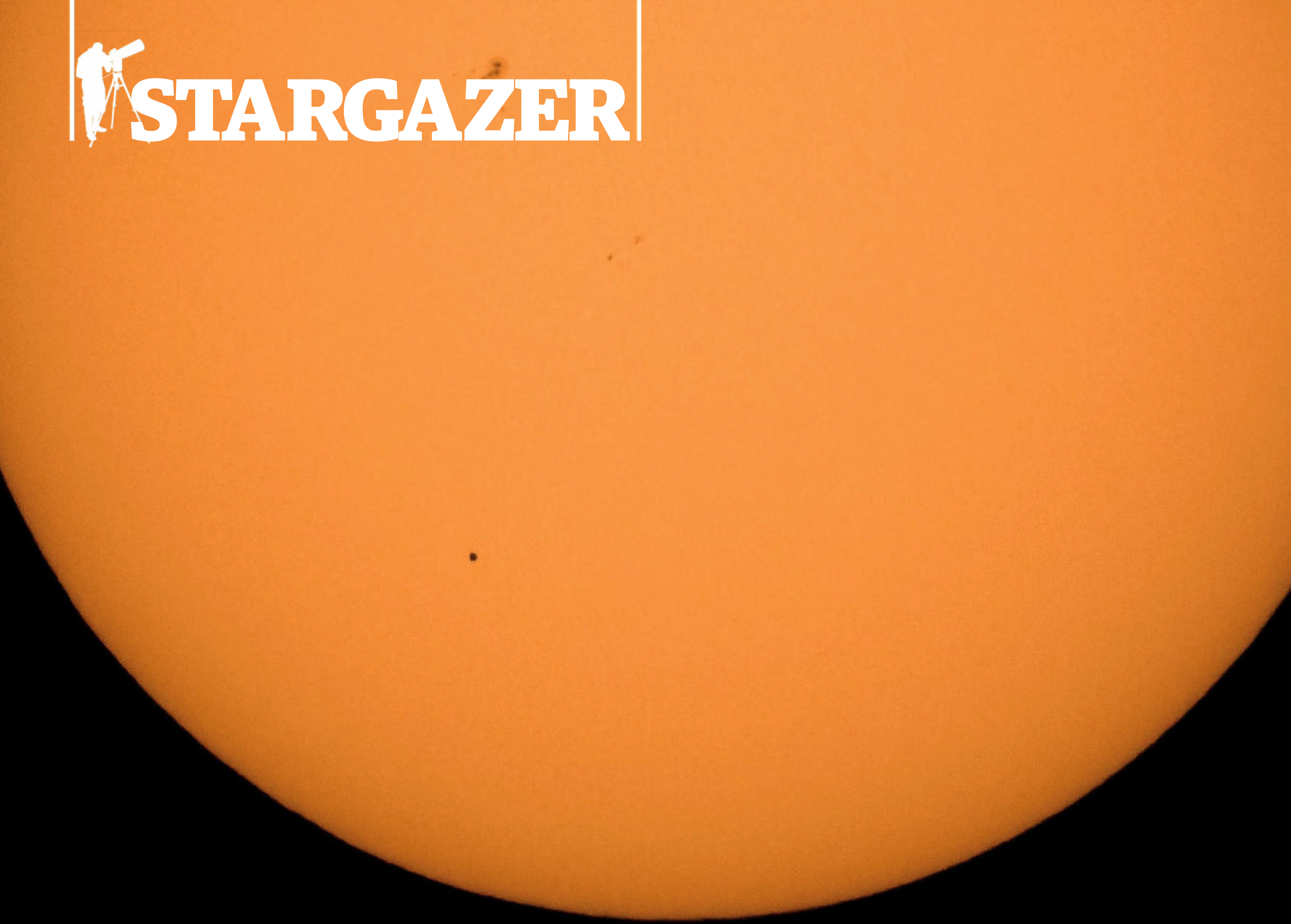
Dr Giuseppe Mitri is a senior researcher at the International Research School of Planetary Sciences



The Huygens lander reached Titan's surface in 2005

©ESA

STARGAZER



© NASA

Mercury's transit of the Sun

On the afternoon of 11 November something quite rare will be happening in the sky - but you'll need special observing techniques and equipment if you're going to see it. Here's our guide

What is happening?

Sky-watchers across the UK and around the world will be crossing their fingers for a cloud-free sky on the afternoon of 11 November to allow them to see one of the rarest events in astronomy. Between 12:36 and 18:04 on that day the Sun, Earth and the planet Mercury will be perfectly aligned. Despite what the internet's doom-mongers will inevitably predict, this alignment won't result in any Hollywood disaster movie shenanigans - there'll be no earthquakes, tidal waves or interdimensional portals opening - but it will mean that for a brief time we'll be able to see Mercury moving across the face of the Sun, silhouetted against it and looking like a tiny, perfect black dot. This is called a transit, and from our viewing point here on Earth only Mercury and Venus can transit the Sun, because they are closer to it than us. The last Mercury transit was in May 2016, and we won't see another one after this until May 2032, so you really don't want to miss it! But if you want to watch it you'll have to be very careful because you'll be looking at the Sun, and that's incredibly dangerous if you don't use the right observing equipment and methods - and a lot of common sense, too.

What will Mercury look like?

During the transit Mercury will be silhouetted against the Sun, so we won't be able to see any features on its surface. Instead what we will see is a black dot moving very, very slowly across the face of the Sun. Some astronomers say that Mercury and Venus look like tiny sunspots during transits, but that's not true: sunspots are extended objects with ragged outlines, dark centres and lighter outer regions. During this transit Mercury will look like a perfect black circle with a razor-sharp edge, but it will be smaller than all but the very smallest sunspots. Although Mercury is a planet half the size of Earth, it is so far away from us that its silhouetted disc will appear to cover just 1/160th of the Sun's face. If you can imagine a tiny spot of black ink on a big white dinner plate, that's what Mercury will look like during the transit.

What will happen during the transit?

Unlike astronomical events such as total solar eclipses, meteor showers and displays of the northern lights, transits of Mercury and Venus are very slow affairs, taking hours to complete. Although Mercury is whipping around the Sun at a speed of almost 50 kilometres (31 miles) per second - so fast that a Mercury year is only 88 days long - it will still take almost six hours to cross the Sun as seen from Earth during the transit. This means that Mercury won't appear to be moving as you look at it during the transit - you'll only notice it has shifted its position if you look at it at different times. This also means that you'll have more chance of seeing it than the minutes-long totality of a total solar eclipse. You can check in on the progress of the transit during the afternoon as and when your schedule allows.

Left Mercury will cross the face of the Sun looking like a small, dark, circular blemish on our star's surface

When will the transit happen?

The 2019 transit of Mercury will begin at 12:36 and end at 18:04 on 11 November, so the whole thing will last for around five-and-a-half hours. Unfortunately the Sun will set for UK observers long before the end of the transit, cutting it short.

And there's more bad news. Because the transit is happening in November and starts after midday, the Sun will already be quite low in the southern sky as the transit begins, and will only get lower in the sky as time passes. To see the transit you'll need to find somewhere with a clear, unobstructed view to the south and as low a horizon as possible. It's definitely a good idea to scout out a viewing spot before the day.

Timings:

First contact:
Mercury's disc will first touch the Sun at 12:36, and will be fully silhouetted against it just a minute or so later. At this time the Sun will already be low in the south, around 17 degrees above the horizon.

Mid-transit:
Mercury will have made it halfway across the Sun at 15:26. By this time the Sun will have dropped a lot lower in the sky, and will be only five degrees above the southwestern horizon.

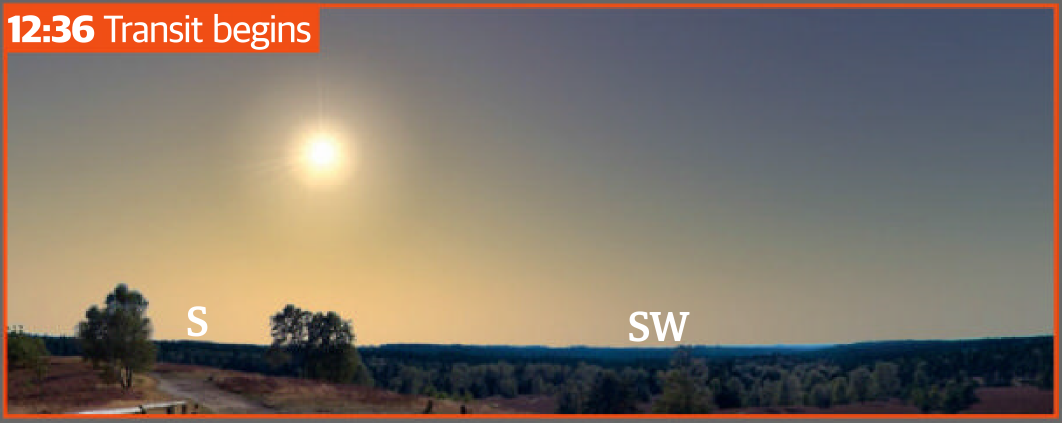
Sunset:
The transit will be cut short for UK observers by sunset, which will occur around 16:15, so we will miss the last two hours of the event. The flatter your southwestern horizon is and the higher up you are, the longer you will be able to follow the transit. After sunset you will still be able to follow the progress of the transit online by watching live-streaming coverage on various observatory websites.

Last contact:
Mercury's disc will leave the Sun's face at 18:04, long after sunset in the UK.

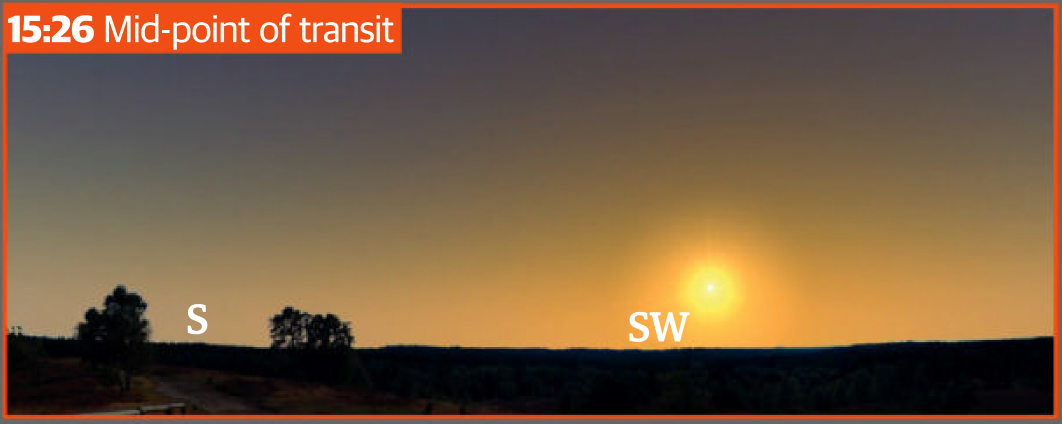
Where to look

The Sun isn't exactly hard to find, but here's where it will be in the sky throughout the transit

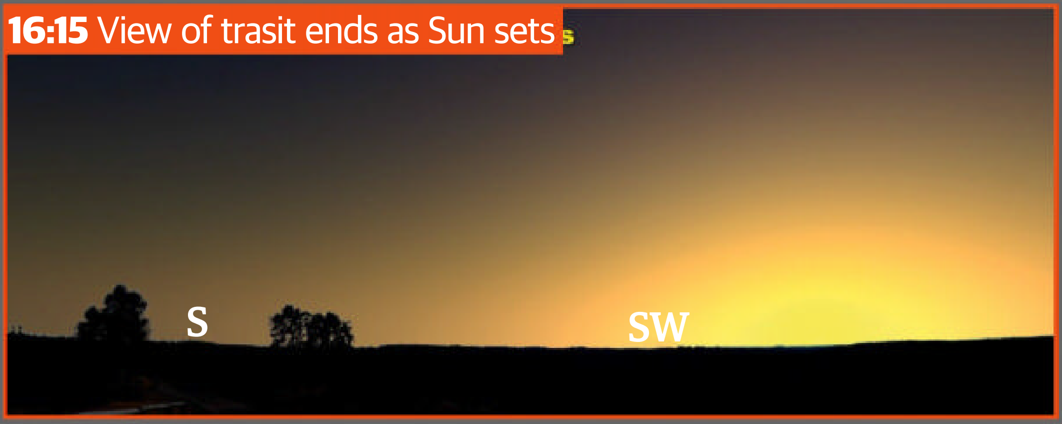
12:36 Transit begins



15:26 Mid-point of transit



16:15 View of trasit ends as Sun sets



How do I watch it?

Transits of Mercury and Venus are fascinating to watch, but potentially extremely dangerous too: you're trying to see a small black dot moving across the brilliant solar disc, so you can't just swing your binoculars or telescope around to the Sun and take a look – do that and you risk poaching your eyeballs in your head. It really is that dangerous. Fortunately there are several totally safe ways of watching a transit, and if you follow them you won't risk permanently damaging or even losing your eyesight altogether.

The safest way is to find out if your local astronomical society is holding a 'transit watch' event. If they are you can go along to it and observe the transit through their equipment in total safety, and will also likely enjoy a much clearer view of it than you'd get from your own back garden. But if that's not an option, what do you do?

Well, you definitely won't be able to see the transit through sunglasses, because they won't darken the Sun's bright disc anywhere near enough to let you see Mercury's silhouette. Unfortunately a pair of special solar eclipse glasses won't be much use either; Mercury's disc will be so tiny your naked eye won't be able to see it. For the same reason the clever trick of using a colander to project images of the Sun onto a wall often utilised during a solar eclipse won't work either.

To see Mercury during the transit you will have to be able to view a magnified image of the Sun, and there are only a few safe ways of doing that

Firstly, by projection. With a bit of practice you can use a pair of binoculars or a telescope to very carefully project an image of the Sun onto a screen, a piece of card or a wall. This method is perfectly safe as long as you don't look through your binoculars or telescope while they're pointed at the Sun – that would result in terrible damage to your eyes.

The other way of observing the transit is by direct viewing. Even if you don't own a specialised solar telescope, it's possible to use a telescope to look directly at the Sun as long as it is fitted with a dedicated 'solar filter'. These pieces of very specialised but relatively inexpensive equipment fit over the front of a telescope like a cap and contain sheets of a special light-but-dense foil-like material that cuts down the Sun's light to almost nothing, allowing the solar disc and any details on it to be viewed directly through the eyepiece. Some produce white images, and others a yellow or even orange image, but all do the same thing. A telescope fitted with this type of Mylar filter can be used to directly observe sunspots and solar eclipses, and is perfect for viewing transits. Solar filters can be bought ready-made, or you can make one yourself by carefully mounting a sheet of the material in a cap measured to fit tightly over the end of your telescope.

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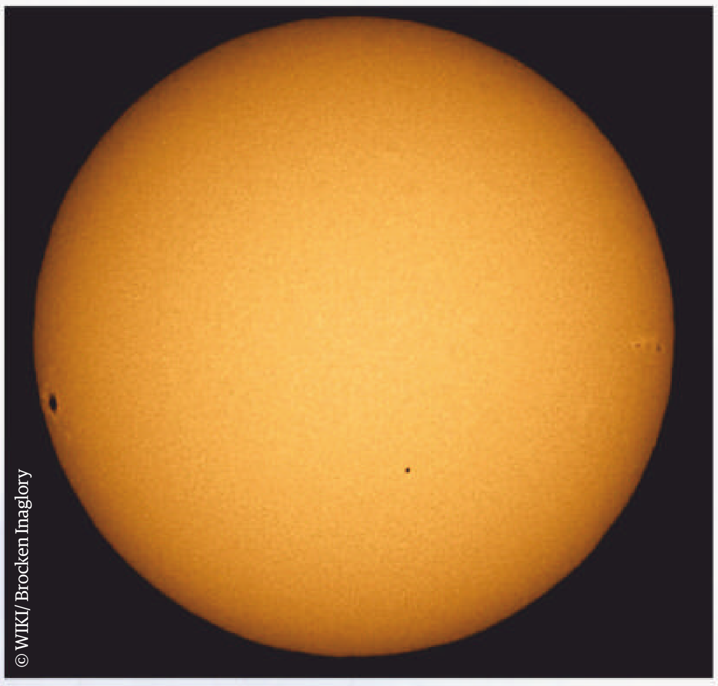
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11 NOV
TAKE CARE!
Transit of Mercury visible from Europe, Africa, the Americas, French Polynesia

18 NOV
The Moon and Messier 44 make a close approach, passing within 1°10' of each other in Cancer

27 NOV
Mercury reaches its highest point in the morning sky, shining at magnitude -0.6

28 NOV
Mercury is at greatest elongation west in the morning sky, shining at magnitude -0.6

28 NOV
The Orionids reach their peak of three meteors per hour

© NASA, ESA

29 NOV
The Moon and Saturn make a close approach, passing within 0°55' of each other Sagittarius

Jargon buster

Conjunction
A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)
Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)
This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Magnitude
An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Opposition
When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Greatest elongation
When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

12 NOV

Asteroid 4 Vesta is at opposition, glowing at magnitude 6.5 in Cetus

12 NOV

The Northern Taurids reach their peak of five meteors per hour

18 NOV

The Leonids reach their peak of 15 meteors per hour

© WIKI/ Juan lacruz

18 NOV

The Pleiades (M45) is well placed for observation in Taurus

25 NOV TAKE CARE!

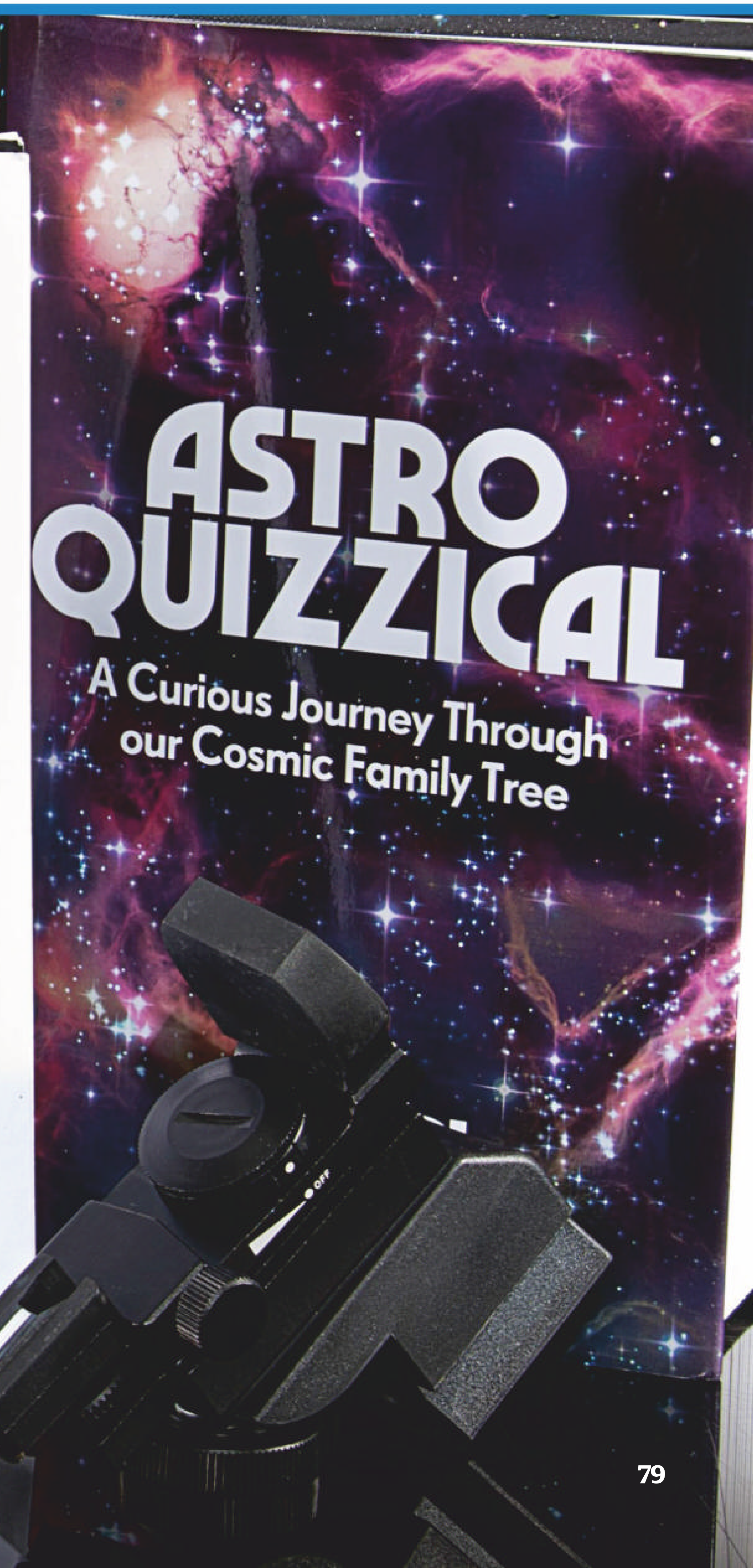
Mercury reaches dichotomy in the morning sky, shining brightly at magnitude -0.4

© WIKI/Kaustav Ghose

29 NOV

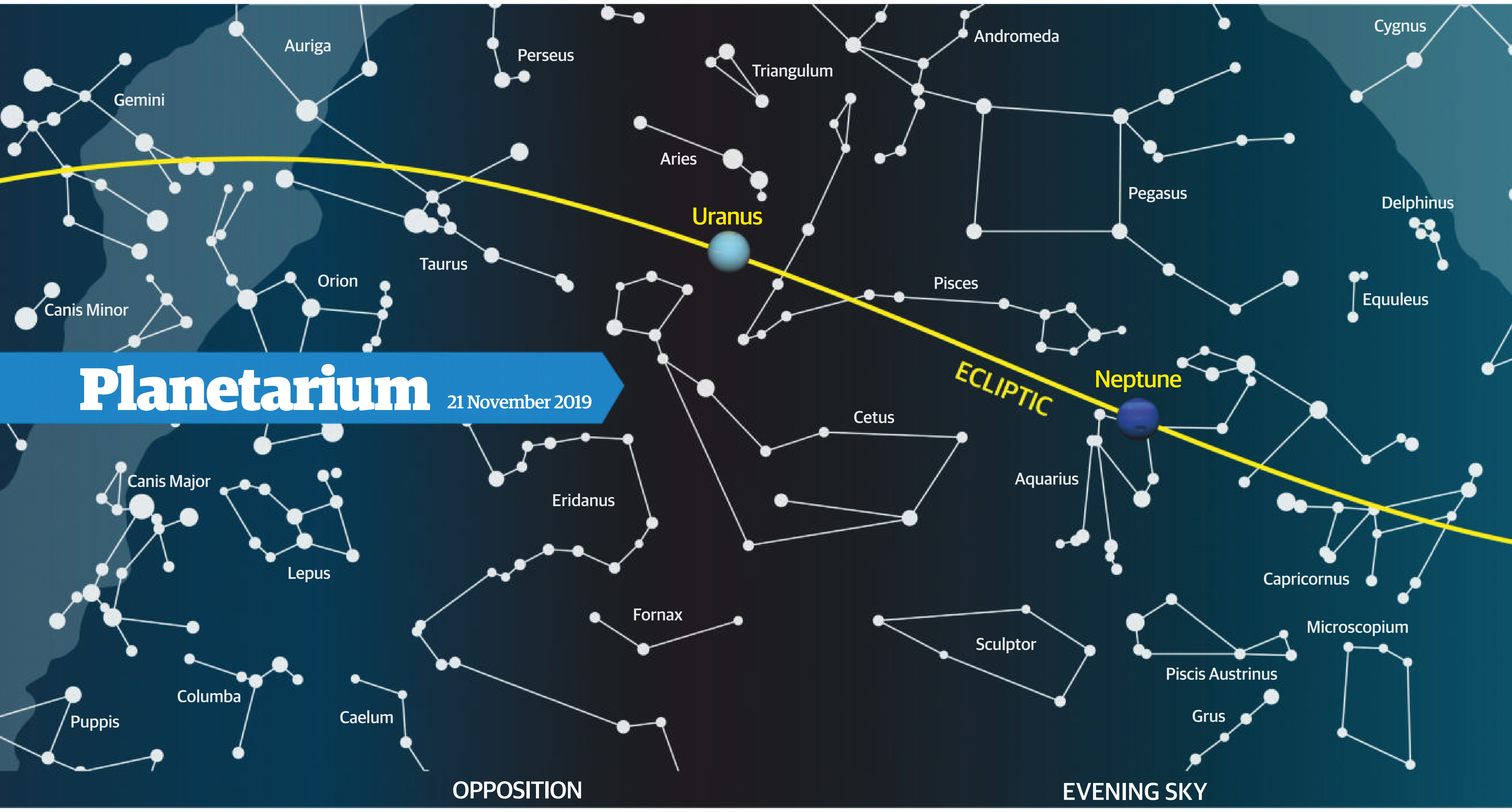
Conjunction between the Moon and Saturn in Sagittarius

- Naked eye
- Binoculars
- Small telescope
- Medium telescope
- Large telescope



Planetarium

21 November 2019



Moon calendar

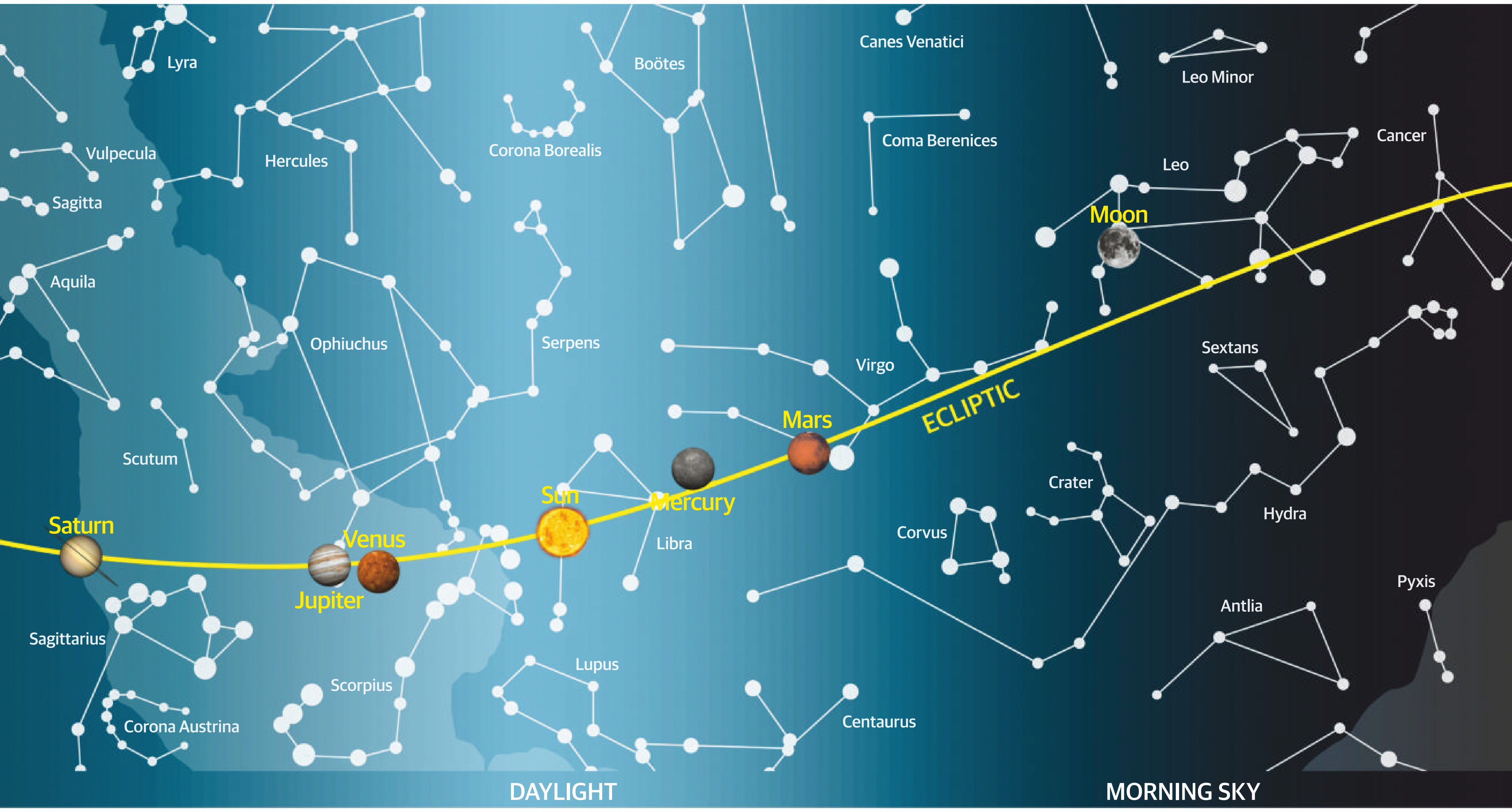
* The Moon does not pass the meridian on 12 November

			7 NOV 80.3% ▼01:03 ▲15:07	**8 NOV** 87.4% ▼02:09 ▲15:25	**9 NOV** 93.1% ▼03:16 ▲15:42	**10 NOV** 97.2% ▼04:23 ▲15:59
11 NOV 99.5% ▼05:31 ▲16:18	**12 NOV** FM --.-% * ▼06:41 ▲16:39	**13 NOV** 99.7% ▼07:52 ▲17:06	**14 NOV** 97.7% ▼09:04 ▲17:39	**15 NOV** 93.4% ▼10:12 ▲18.21	**16 NOV** 87.0% ▼11:14 ▼19:14	**17 NOV** 78.6% ▼12:06 ▲20:19
18 NOV 68.6% ▼12:49 ▲21:32	**19 NOV** LQ 57.4% ▼13:23 ▲22:50	**20 NOV** 45.7% ▼--:-- ▲13:51	**21 NOV** 34.1% ▲00:11 ▼14:15	**22 NOV** 23.2% ▲01:33 ▼14:36	**23 NOV** 13.9% ▲02:55 ▼14:57	**24 NOV** 6.6% ▲04:18 ▼15:19
25 NOV 2.0% ▲05:40 ▼15:44	**26 NOV** NM 0.1% ▲07:02 ▼16:33	**27 NOV** 1.0% ▲08:20 ▼16:49	**28 NOV** 4.6% ▲09:31 ▼17:34	**29 NOV** 10.2% ▲10:32 ▼18:27	**30 NOV** 17.5% ▲11:21 ▼19:28	**1 DEC** 26.0% ▲11:59 ▼20:33
2 DEC 35.3% ▲12:29 ▼21:40	**3 DEC** 44.9% ▲12:53 ▼22:48	**4 DEC** FQ 57.7% ▲13:13 ▼23.54	**5 DEC** 64.2% ▲13:31 ▼--:--			

% Illumination
▲ Moonrise time
▼ Moonset time

FM Full Moon
NM New Moon
FQ First quarter
LQ Last quarter

All figures are given for 00h at midnight (local times for London, UK)



Illumination percentage

	14 NOV	21 NOV	38 NOV	5 DEC
MERCURY	0%	30%	60%	80%
VENUS	90%	90%	90%	90%
MARS	100%	100%	100%	100%
JUPITER	100%	100%	100%	100%
SATURN	100%	100%	100%	100%

Planet positions

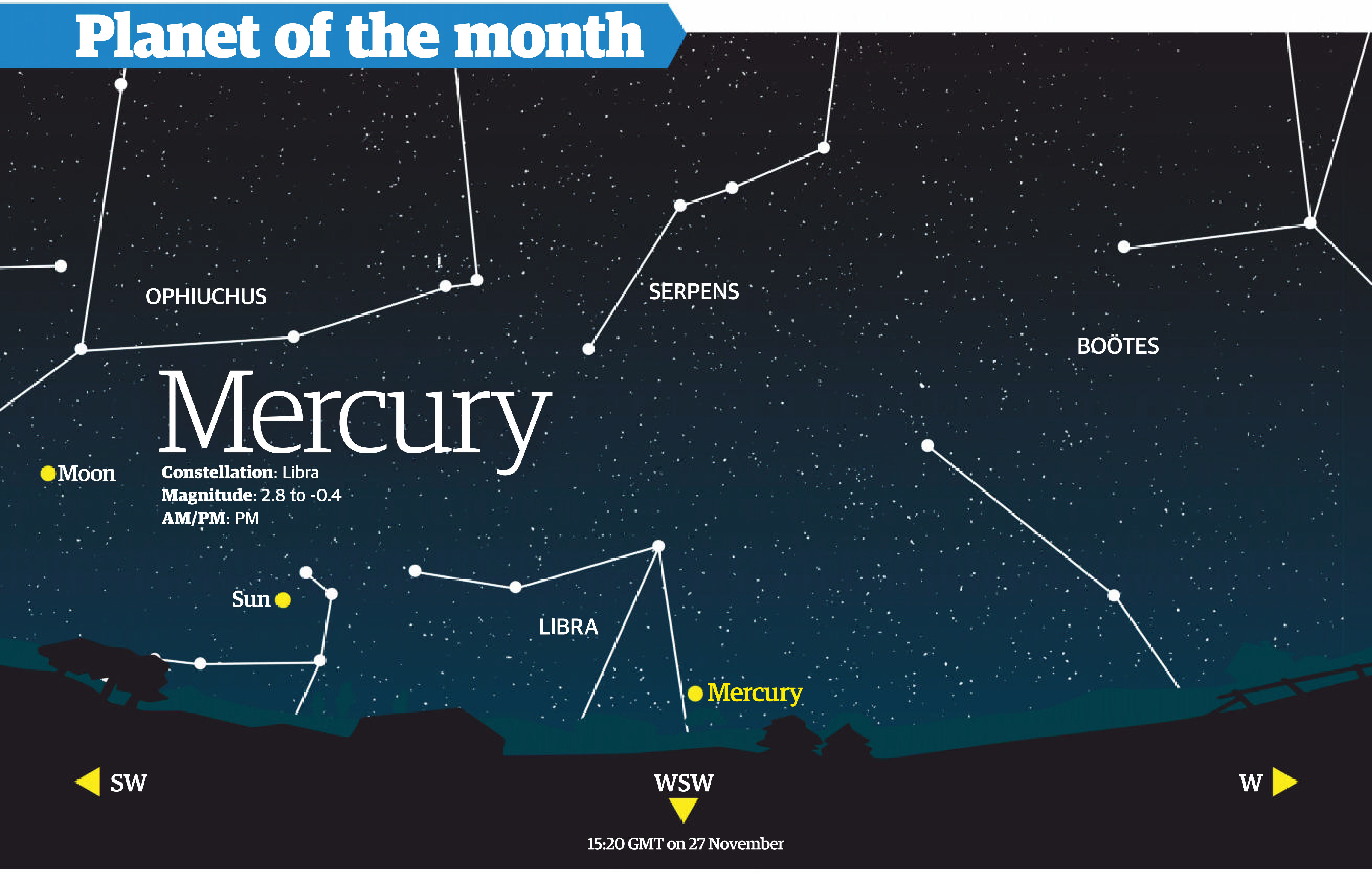
All rise and set times are given in GMT

	Date	RA	Dec	Constellation	Mag	Rise	Set
MERCURY	7 NOV	15h 26m 08s	-20° 16' 57"	Libra	2.6	08:16	16:44
	14 NOV	14h 53m 38s	-15° 44' 35"	Libra	4.2	06:49	16:12
	21 NOV	14h 38m 28s	-13° 02' 00"	Libra	0.3	05:51	15:44
	28 NOV	14h 54m 02s	-14° 06' 34"	Libra	-0.6	05:45	15:26
	5 DEC	15h 26m 39s	-16° 55' 20"	Libra	-0.6	06:06	15:15
VENUS	7 NOV	16h 16m 36s	-21° 52' 51"	Scorpius	-3.9	09:17	17:24
	14 NOV	16h 53m 42s	-23° 25' 19"	Ophiuchus	-3.9	09:37	17:23
	21 NOV	17h 31m 29s	-24° 24' 14"	Ophiuchus	-3.9	09:54	17:26
	28 NOV	18h 09m 39s	-24° 47' 22"	Sagittarius	-3.9	10:08	17:34
	5 DEC	18h 47m 49s	-24° 33' 44"	Sagittarius	-3.9	10:17	17:46
MARS	7 NOV	13h 21m 17s	-07° 42' 23"	Virgo	1.8	05:01	15:50
	14 NOV	13h 38m 27s	-09° 25' 50"	Virgo	1.8	05:00	15:31
	21 NOV	13h 55m 51s	-11° 06' 24"	Virgo	1.7	04:58	15:12
	28 NOV	14h 13m 32s	-12° 43' 26"	Virgo	1.7	04:57	14:53
	5 DEC	14h 31m 29s	-14° 16' 17"	Virgo	1.7	04:56	14:35
JUPITER	7 NOV	17h 35m 02s	-23° 07' 49"	Ophiuchus	-1.9	10:44	18:34
	14 NOV	17h 41m 13s	-23° 11' 51"	Ophiuchus	-1.9	10:23	18:12
	21 NOV	17h 47m 38s	-23° 15' 00"	Sagittarius	-1.9	10:02	17:51
	28 NOV	17h 54m 15s	-23° 17' 10"	Sagittarius	-1.8	09:42	17:29
	5 DEC	18h 01m 01s	-23° 06' 32"	Sagittarius	-1.8	09:21	17:08
SATURN	7 NOV	19h 07m 36s	-22° 24' 11"	Sagittarius	0.6	12:11	20:11
	14 NOV	19h 10m 00s	-22° 20' 51"	Sagittarius	0.6	11:46	19:46
	21 NOV	19h 12m 37s	-22° 29' 11"	Sagittarius	0.6	11:20	19:22
	28 NOV	19h 15m 27s	-22° 12' 31"	Sagittarius	0.6	10:55	18:58
	5 DEC	19h 18m 28s	-22° 07' 32"	Sagittarius	0.6	10:30	18:34

This month's planets

Now's the perfect time to catch the elusive Mercury as it gets ready to pass in front of the Sun

Planet of the month



Mercury

Constellation: Libra
Magnitude: 2.8 to -0.4
AM/PM: PM

15:20 GMT on 27 November

Although it is usually so hard to see, this is a very big month for the closest planet to the Sun and for those who like to observe it. As far as observing is concerned, Mercury is one of the 'forgotten' worlds of the Solar System. Along with distant Uranus and Neptune, it is considered by many amateur astronomers to be too difficult to see.

At the start of the month that is the case, with Mercury too close to the Sun to be visible in the sky, setting only a few minutes after our star and growing closer and closer to it every day. But bizarrely, when Mercury actually moves directly in front of the blindingly bright Sun on the afternoon of 11 November it will become easier to see...

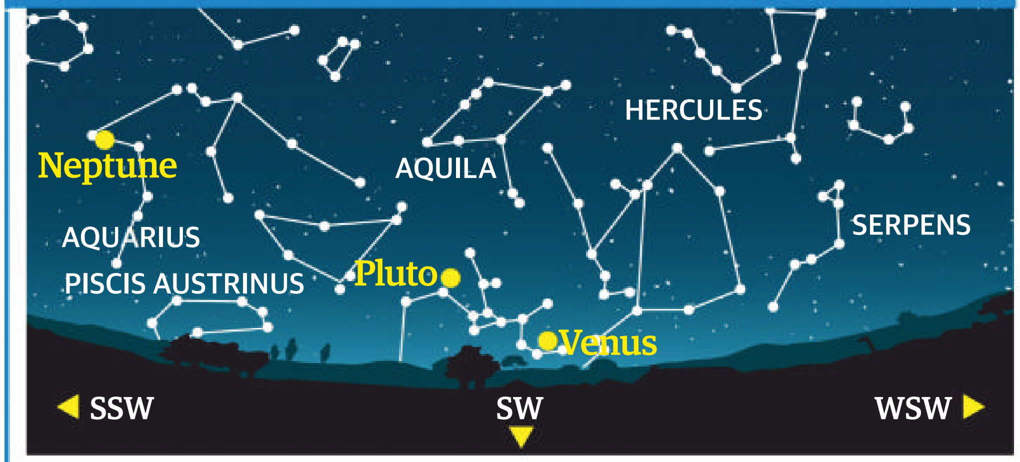
Seen from Earth, only Mercury and Venus can move across the face of the Sun in this way and be silhouetted against it, because they are closer to it than our planet is. Astronomers call such an event a 'transit', and just after 12:30 on the afternoon of 11 November a transit of Mercury will occur. Unlike transits of Venus, which take only a couple of hours from start to finish, Mercury transits take a long time. For five-and-a-half hours after its 'first contact' with its limb, Mercury will slowly drift across the face of the Sun until it moves off the disc at just after 18:00. As seen from the UK the Sun will be setting around 4:15, long before the transit ends, so we'll miss the last part, but we'll still have more than four hours of it to enjoy. Because Mercury is so small and so far away it will only look like a tiny black dot against the Sun, almost like a tiny, perfectly round sunspot.

If you want to know more about this very exciting event we have a special feature on the Mercury transit on page 76 of this issue, with full information about timings, observing tips and advice on how to watch the transit safely.

After the excitement of the transit has died down Mercury will climb up into the morning sky, becoming an easy-to-see 'morning star' in the east, to the lower left of fainter Mars. Look out for a very thin sliver of a waning Moon to the left of Mercury before sunrise on the morning of 25 November.

Mercury will be at its best two days later before dawn on the morning of 27 November, when it will rise two hours before the Sun and will be very obvious to the naked eye, looking like a copper-coloured spark shining above the trees and rooftops. That will be a great morning to try and photograph it with a DSLR camera mounted on a steady tripod.

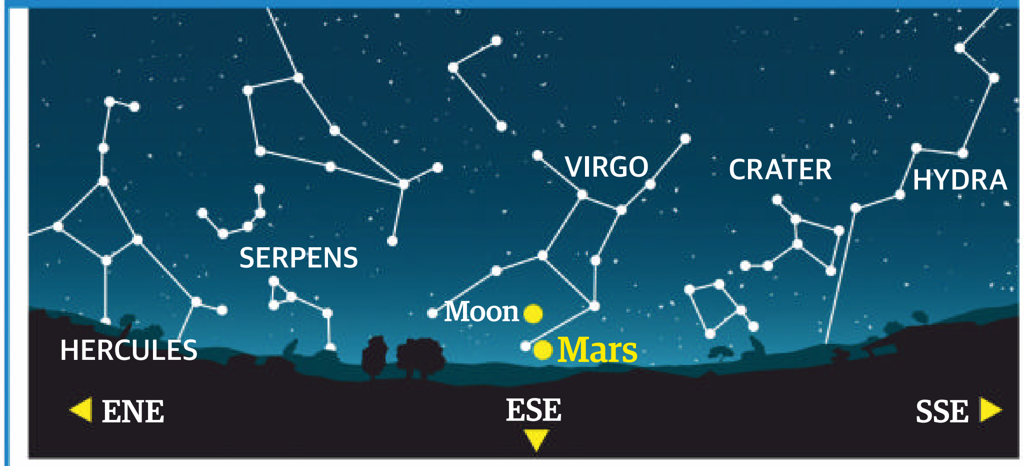
Venus 16:30 GMT on 25 November



Constellation: Scorpius
Magnitude: -3.0
AM/PM: PM

Venus is an 'evening star' this month, hanging low in the southwest sky, although its visibility will improve as the month passes. At the start of the month it will lie to the lower right of Jupiter, but the two planets will grow closer and closer each evening until they appear to pass between 22 and 25 November.

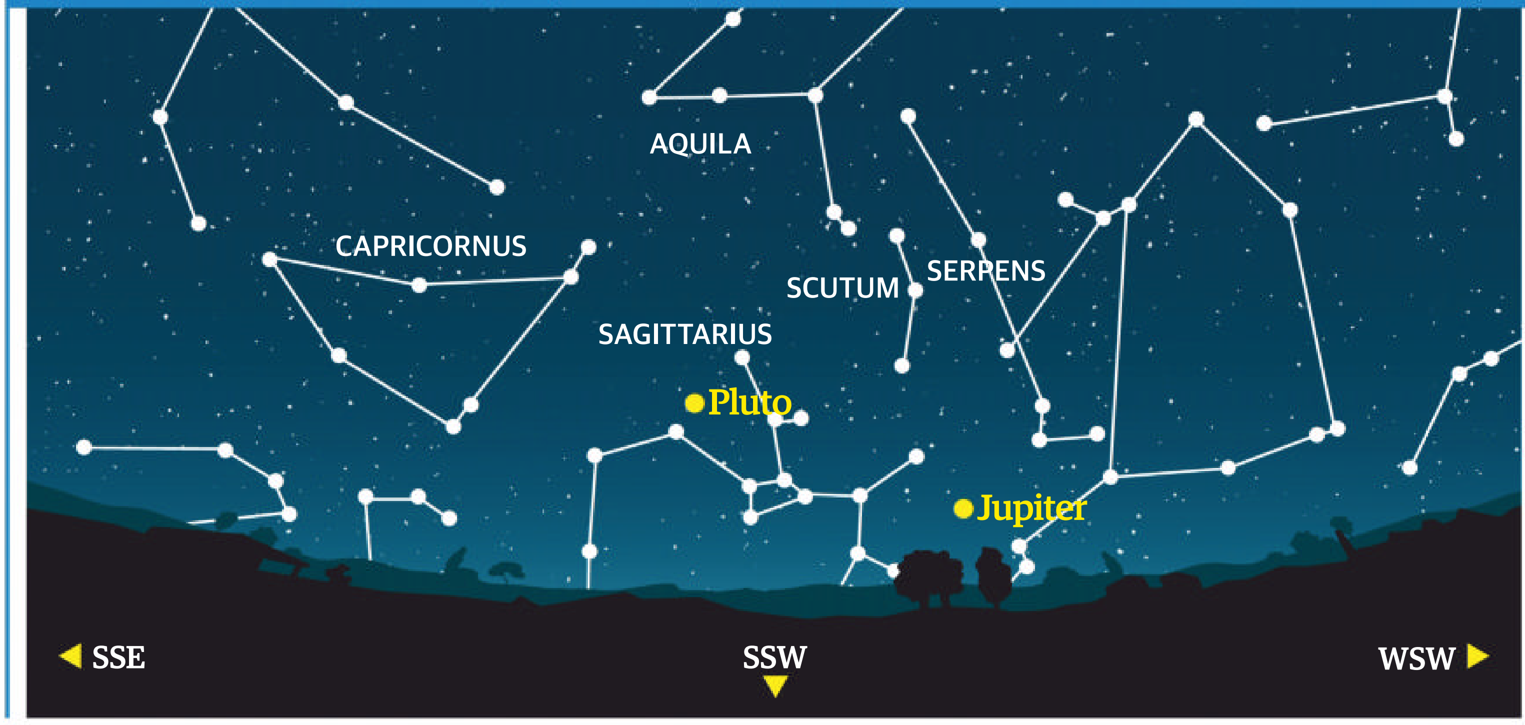
Mars 05:30 GMT on 24 November



Constellation: Virgo
Magnitude: 1.8
AM/PM: AM

Mars is quite a faint and unimpressive 'morning star' this month, shining in Virgo just above that constellation's brightest star, Spica. At the start of our observing period the Red Planet rises not long before the Sun, but by early December it is rising well before it, and will be an easy naked-eye object.

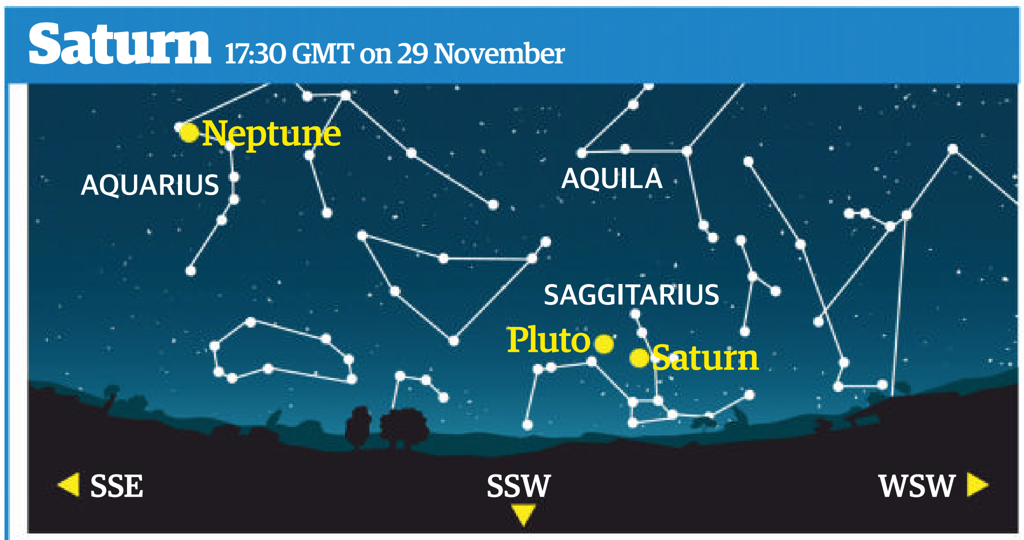
Jupiter 16:30 GMT on 24 November



Constellation: Ophiuchus
Magnitude: -1.9
AM/PM: PM

Jupiter will be an easy naked-eye object through the month, looking like a bright star. At the start of November you'll see it low in the SSW as soon as the sky starts to darken, shining between Saturn, some distance to its upper left, and Venus, down to its lower right. You won't have long to observe it because it will be setting just two hours after the Sun. As the days pass Venus will begin to climb up towards Jupiter, and the two planets will be so close together between 23 and 24 November that they will look like a 'double star' in the sky, a really lovely sight in binoculars if you have them.

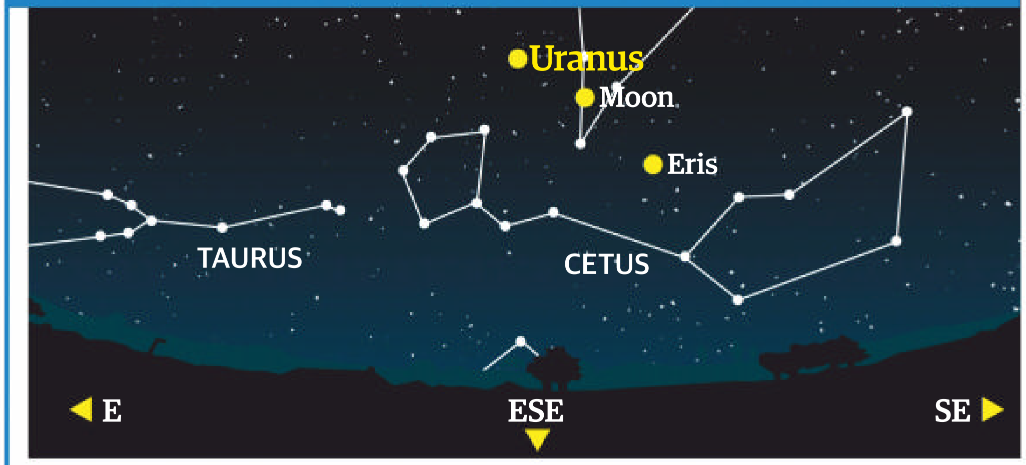
Saturn 17:30 GMT on 29 November



Constellation: Sagittarius
Magnitude: 0.6
AM/PM: PM

Like Jupiter, which will be shining down to its lower right, Saturn will be an easy naked-eye star in the post-sunset sky. At the start of our observing period Saturn will set three hours after the Sun, but by early December it will be setting just two hours after it, so its visibility will worsen during the month.

Uranus 19:20 GMT on 10 November



Constellation: Aries
Magnitude: 5.7
AM/PM: PM

Uranus will be an evening object this month, rising at around the same time as the Sun sets, so visible all through the evening and night until the approach of dawn washes it from the sky. Look for the almost-full Moon shining around eight degrees to Uranus' lower right after dark on 10 November.

Top tip!

We can see Mare Orientale sometimes when the wobbling - or libration - of the Moon briefly tilts it towards us.

Moon tour

Far side of the Moon

The wonders that can be found on the mysterious face, unseen from Earth

Although astronomers who observe faint deep-sky objects - the speckled clumps of star clusters, the misty clouds of star-forming nebulae and the graceful, smoky swirls of distant galaxies - might curse its blinding, silvery light, we really are lucky to have the Moon in our night sky. After all, it's like having a small, alien planet on our doorstep, with a ridiculous number of fascinating mountains, valleys and craters to explore whenever we feel like it, or at least when our sky is clear. But even the most enthusiastic Moon-watcher sometimes feels frustrated that we only ever see one side of it.

Since the Moon is tidally locked with Earth it spins around on its axis at the same speed at which it orbits our planet, so we always see the same side. 'Our' side is magnificent, but you know what us humans are like - we're a restless bunch. We always want to see what's around the corner or over the horizon, and the limb of the Moon is a far horizon we can never reach and never look over. Every Moon-watcher has looked up at the Moon at some point and wished that just once they could see the far side with their own eyes and through their telescope.

The side of the Moon which is always hidden from our view is often called the 'dark side', but it is not dark, at least not all the time as many people think. When you actually think about it, when the Moon is new for us it must be full from the other side. So why is it called the dark side so often when it gets just as much sunlight as our side? Well, some people genuinely think it is always in darkness. Other people think it refers to the way it is dark in terms of its visibility for us, so let's go with that.

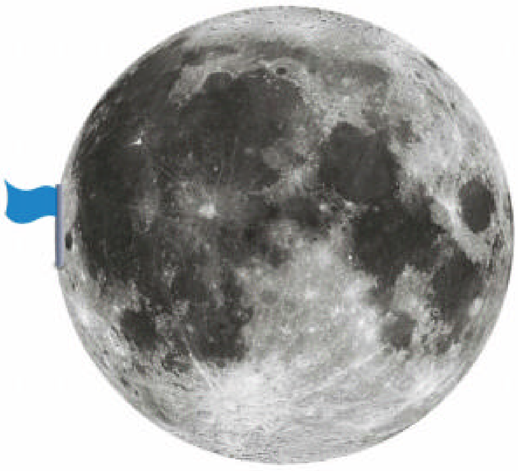
Some people have seen the far side of the Moon in person: some of the Apollo astronauts looked down on it from their cramped capsules with wonder as it slid beneath them. Moon-orbiting satellites have now photographed the far side of the Moon in as much detail as the near side, too. But looking at photographs isn't the same thing as actually seeing somewhere, is it? If you could magically reach up into the sky, grab the Moon and twist it around like a light bulb, what would you see?

The first thing you'd notice is that there are none of the big, dark areas - the seas - that are painted on our side. In fact, while 13 per cent of the near side is covered with the dark lava plains of mare, only one per cent of the far side is. Looking at the far side from your garden you would only really be able to see one small sea - Mare Moscoviense - up near the top left of the Moon.

You would be able to see lots of craters though, some of them huge. Almost the whole of the south polar region of the Moon is one huge crater, the South Pole-Aitken Basin - an impact feature 2,500 kilometres (1,553 miles) across and 13 kilometres (eight miles) deep which was blasted out by an impact billions of years ago.

While it's not strictly on the side of the Moon directly opposite ours, if you turned the Moon further around you would be able to see Mare Orientale, the 'Eastern Sea'. Made up of three rings of jagged mountains, this spectacular impact feature was blasted out of the Moon more than 3.8 billion years ago. If Mare Orientale was turned directly towards us, the Moon would look like a giant eyeball in the sky, staring down at us - a bloodshot eye during a total lunar eclipse, imagine that...

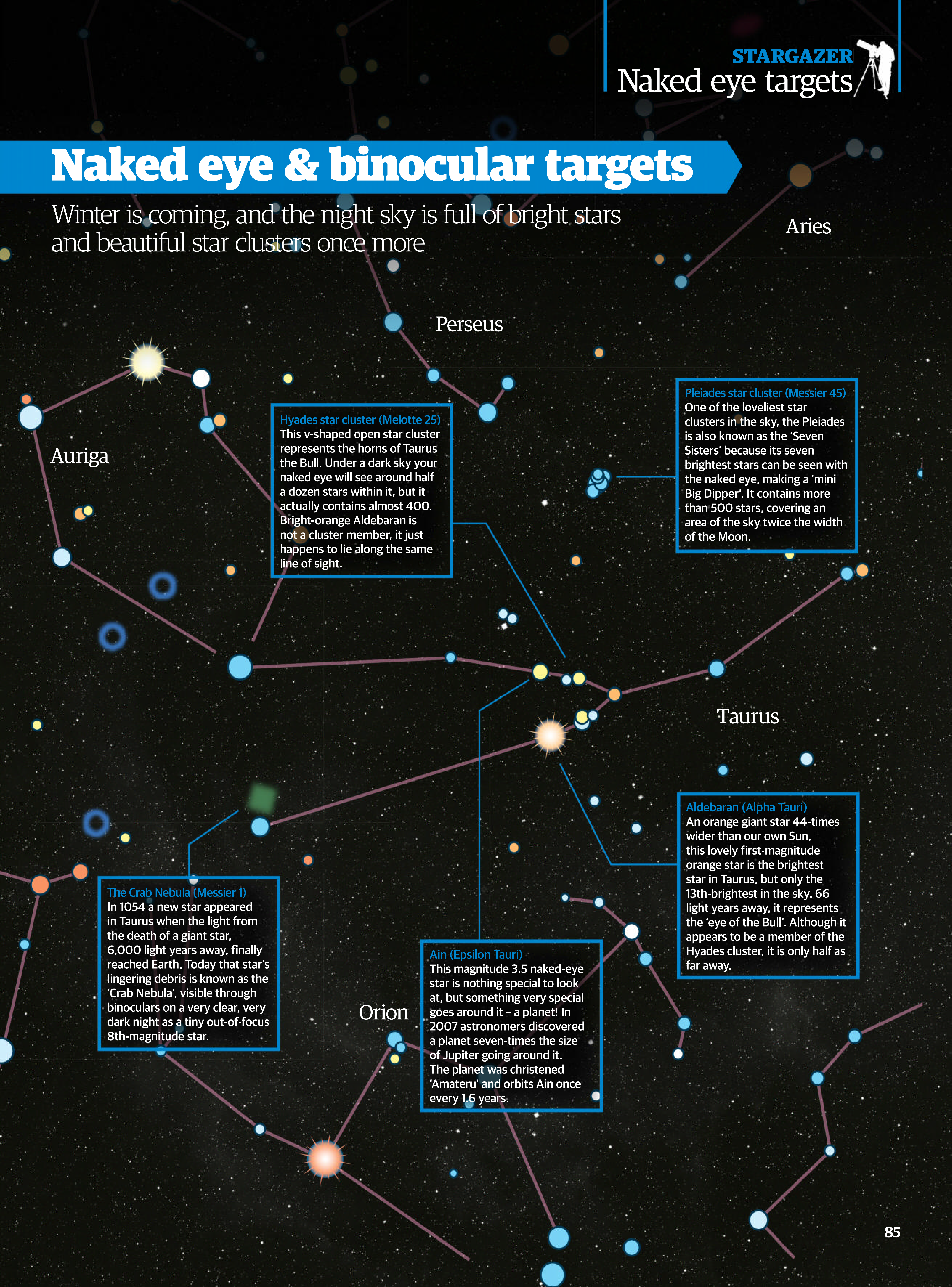
But before you feel too cheated, consider this. If you enjoy looking at those craters with bright rays of debris streaking away from them, like the celebrity craters Tycho, Copernicus and Kepler, you wouldn't see them if we swapped sides. At full Moon you would see some impressive rays streaking away from the crater Jackson, over to the right of Mare Moscoviense. With no dark seas for meteoroids to hit and spray with debris, the far side is very poor for rays compared to our side.



© NASA

Naked eye & binocular targets

Winter is coming, and the night sky is full of bright stars and beautiful star clusters once more



Hyades star cluster (Melotte 25)
This v-shaped open star cluster represents the horns of Taurus the Bull. Under a dark sky your naked eye will see around half a dozen stars within it, but it actually contains almost 400. Bright-orange Aldebaran is not a cluster member, it just happens to lie along the same line of sight.

Pleiades star cluster (Messier 45)
One of the loveliest star clusters in the sky, the Pleiades is also known as the 'Seven Sisters' because its seven brightest stars can be seen with the naked eye, making a 'mini Big Dipper'. It contains more than 500 stars, covering an area of the sky twice the width of the Moon.

Aldebaran (Alpha Tauri)
An orange giant star 44-times wider than our own Sun, this lovely first-magnitude orange star is the brightest star in Taurus, but only the 13th-brightest in the sky. 66 light years away, it represents the 'eye of the Bull'. Although it appears to be a member of the Hyades cluster, it is only half as far away.

The Crab Nebula (Messier 1)
In 1054 a new star appeared in Taurus when the light from the death of a giant star, 6,000 light years away, finally reached Earth. Today that star's lingering debris is known as the 'Crab Nebula', visible through binoculars on a very clear, very dark night as a tiny out-of-focus 8th-magnitude star.

Ain (Epsilon Tauri)
This magnitude 3.5 naked-eye star is nothing special to look at, but something very special goes around it – a planet! In 2007 astronomers discovered a planet seven-times the size of Jupiter going around it. The planet was christened 'Amateru' and orbits Ain once every 1.6 years.

Deep sky challenge

Celestial gems of November

A challenging hunt for a treasure trove of treats in the icy late-autumn sky

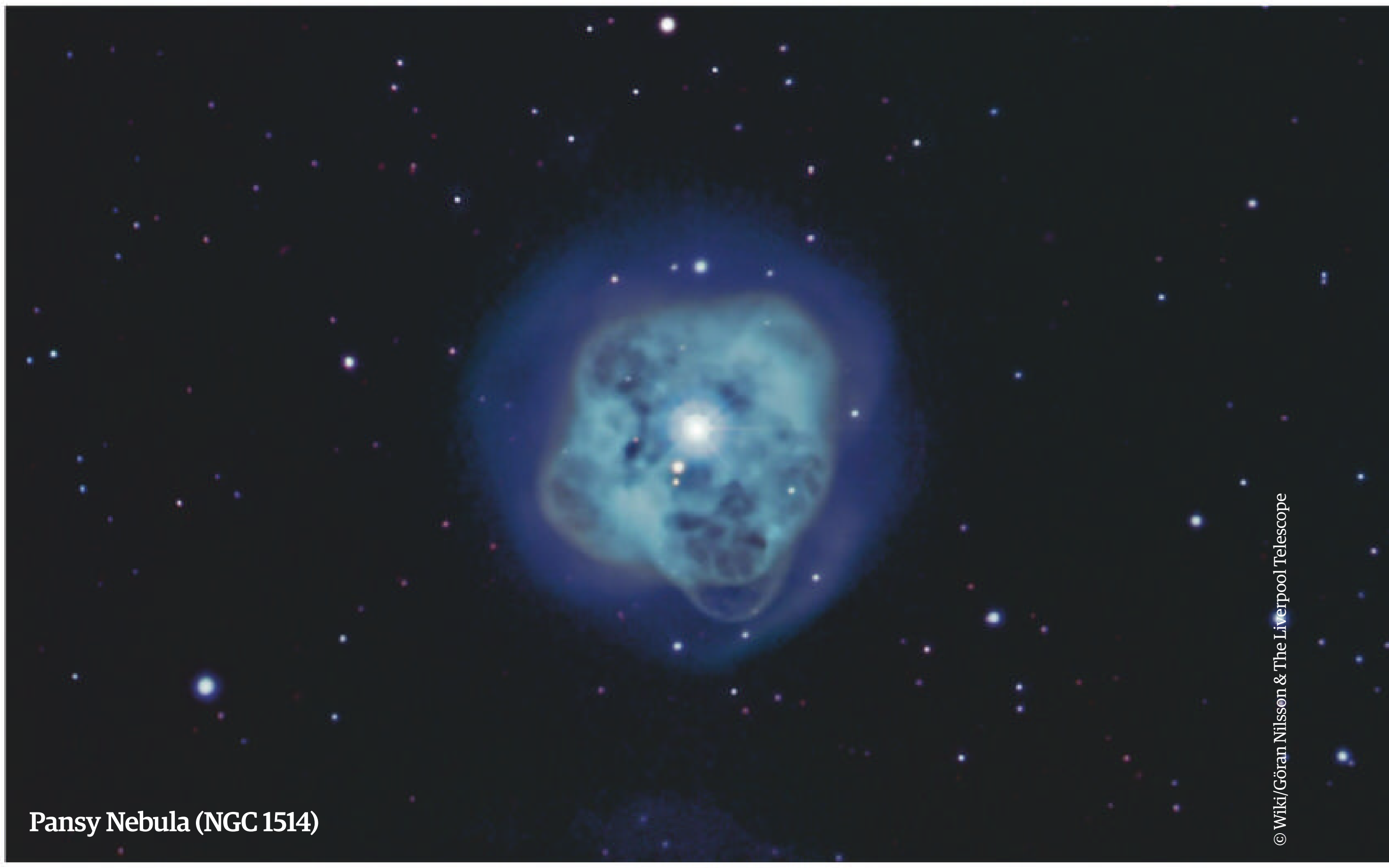
Crab Nebula (Messier 1)

© NASA, ESA

There are many bright and obvious deep-sky objects in the sky around this time of year that telescopes are drawn to over and over again. The Orion Nebula is a stunning sight through any telescope large or small, and the Pleiades star cluster is a glittering spectacle through any eyepiece too. But if you can bear to drag your frost-bitten eyes away from those celebrity objects there are other sights well worth your attention, especially in and around Taurus.

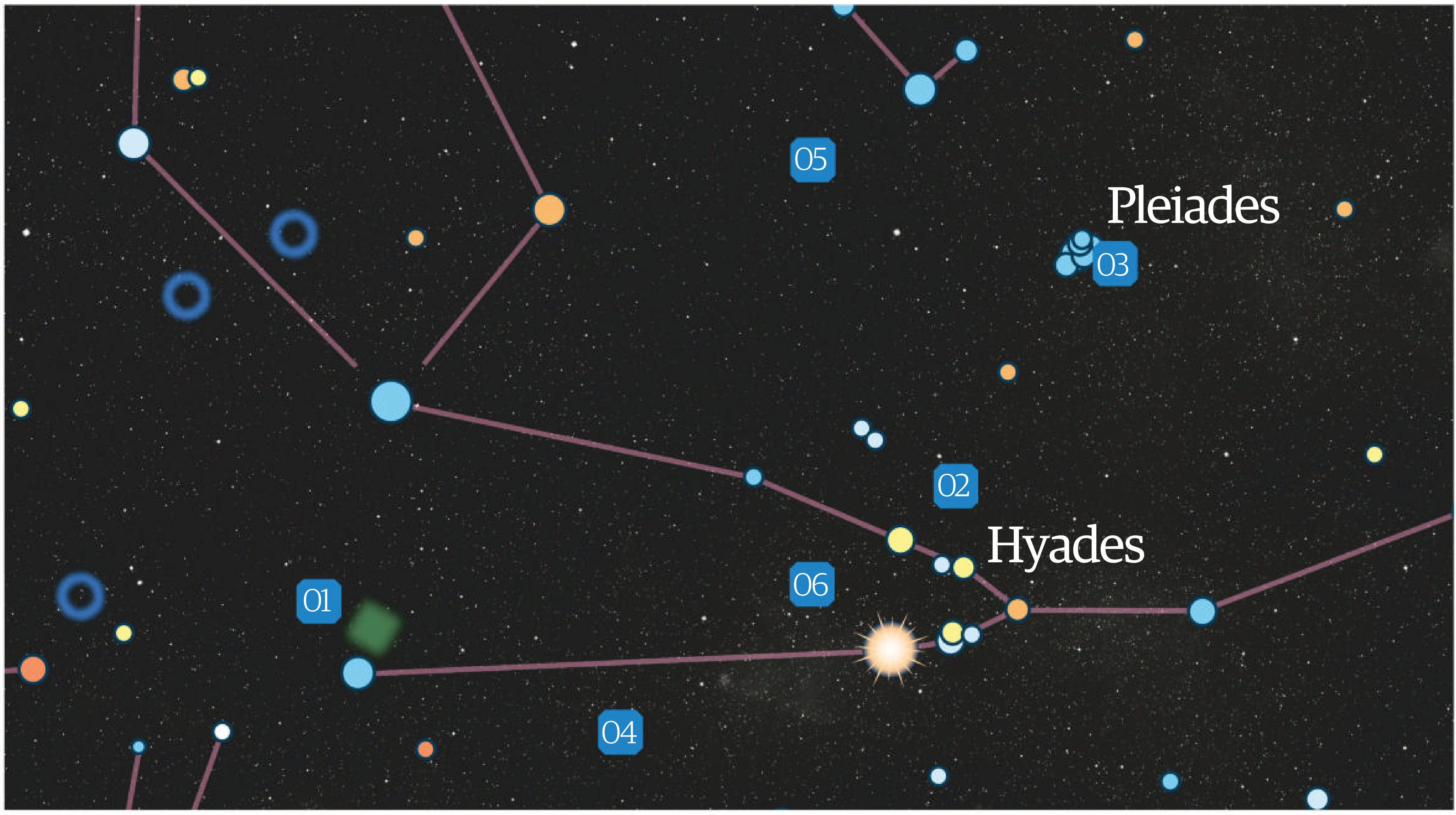
The Crab Nebula has to be on every deep-sky observer's must-see list as Christmas approaches, and with a large telescope a lot of detail emerges out of its misty smudge - even its vaguely crab-like shape. Train your large telescope on the Pleiades, fitted with your highest quality high-power eyepiece, and you'll see its brighter stars are embedded in clouds of pale grey-blue nebulosity.

Elsewhere, close to the sharply pointed horns of Taurus, the little-known 'Pirate Moon Cluster' is overshadowed by its brighter, attention-seeking neighbours, but again it is well worth a look through a large telescope on a night with good clarity and no Moon drowning the sky with its light.



Pansy Nebula (NGC 1514)

© Wiki/Göran Nilsson & The Liverpool Telescope



© Wil Tirion

1 The Crab Nebula (Messier 1)

This magnitude 8.0 smudge is all that remains of a star that blew up, visible as a supernova in the year 1054. A large telescope and high magnification shows delicate tendrils of gas and dust within it.

2 Hind's Variable Nebula (NGC 1555)

Close to the star T Tauri, this small reflection nebula looks like a very faint, misty curve of light through a large telescope, but requires perfect conditions on a Moon-free night to see it.

3 Nebulosity in the Pleiades (Messier 45)

A large telescope's wide-field eyepiece is necessary to show the ghostly clouds of gas and dust which the Pleiades star cluster is currently flying through, 430 light years away from Earth.

4 NGC 1807 and 1817

These two ninth-magnitude open clusters are known to some observers as 'The Poor Man's Double Cluster'. Your best view will be through your large telescope's best medium-power eyepiece.

5 Pansy Nebula (NGC 1514)

This ninth-magnitude planetary nebula requires high magnification through a large telescope and a very dark sky to reveal bright blobs inside it.

6 Pirate Moon Cluster (NGC 1647)

This scattered open cluster is neglected by many observers due to its proximity to the Hyades and Pleiades, but low magnification through a large telescope reveals its 100-plus stars.

Pirate Moon Cluster (NGC 1647)

© Wiki/Roberto Mura

The Northern Hemisphere

The constellations of autumn are slowly being pushed from the night sky by those of winter, offering a much wider observing range

Along with the planetary members of our Solar System making their way along the ecliptic, a display of deep-sky objects - including a selection of elliptical and spiral galaxies - are there for astronomers to enjoy.

The stars of winter have started to make themselves known. Orion, Cetus, Canis Major and Taurus in particular make a dramatic entrance in the darker skies. The Andromeda Galaxy (M31) and its satellites are still easy prey for those with telescopes with at least a small aperture, while all-time favourite the Orion Nebula (M42) is easy to spot with the naked eye from a dark-sky site, or with binoculars and telescopes in light-polluted skies.

Using the sky chart

This chart is for use at 22:00 (GMT) mid-month and is set for 52° latitude.

01 Hold the chart above your head with the bottom of the page in front of you.

02 Face south and notice that north on the chart is behind you.

03 The constellations on the chart should now match what you see in the sky.

Magnitudes

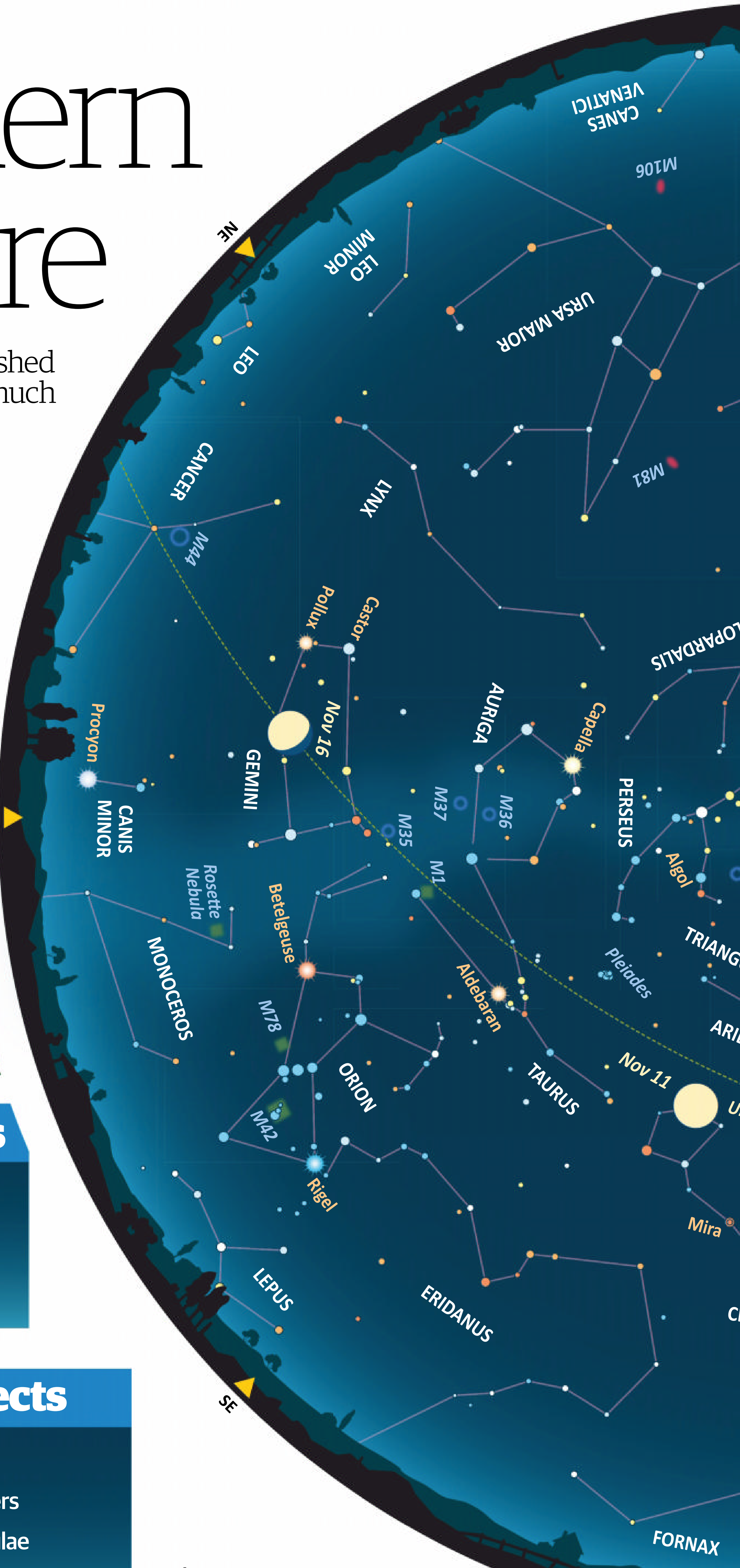
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- Fainter
- Variable star

Spectral types

O-B	G
A	K
F	M

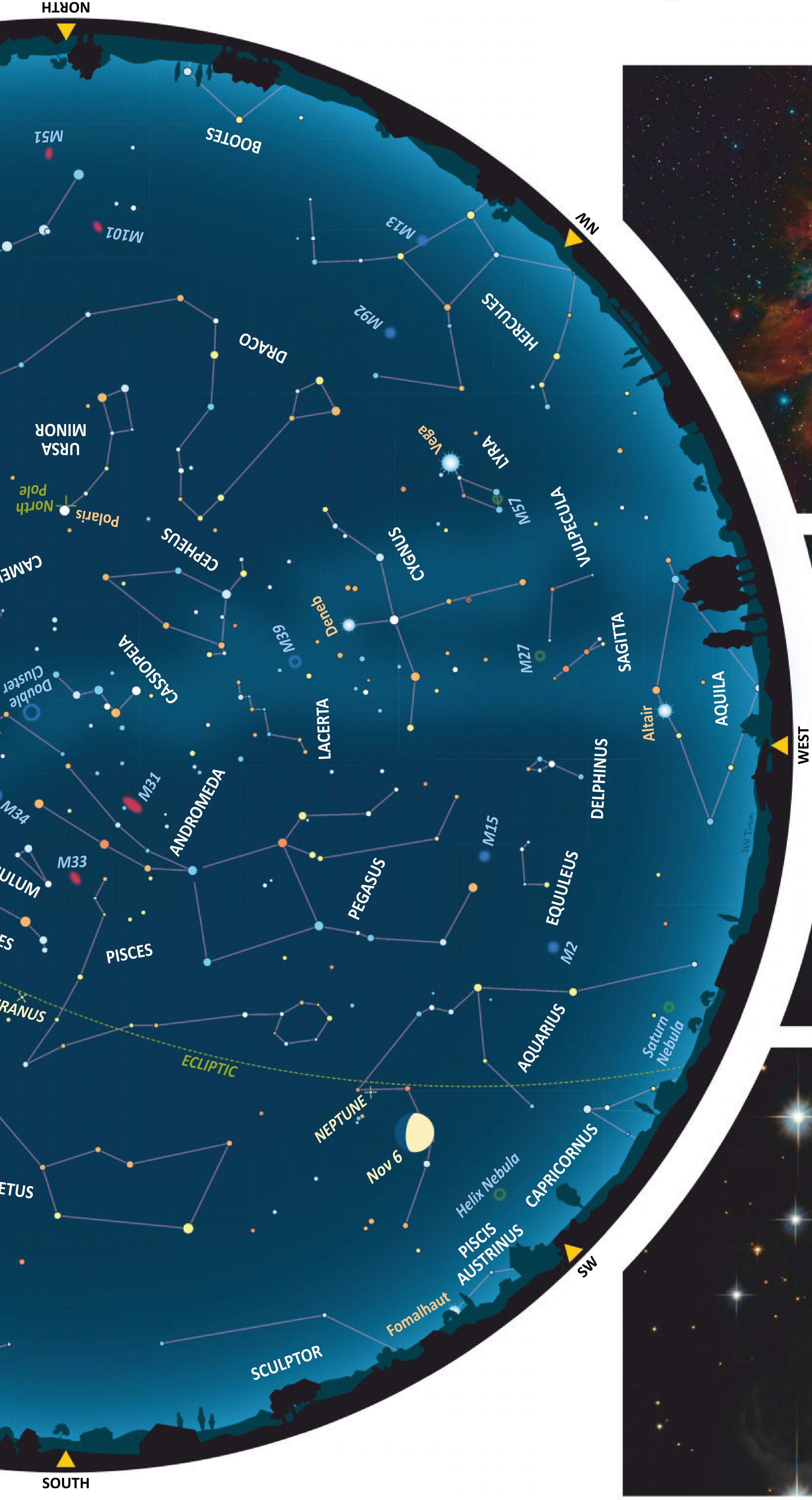
Deep-sky objects

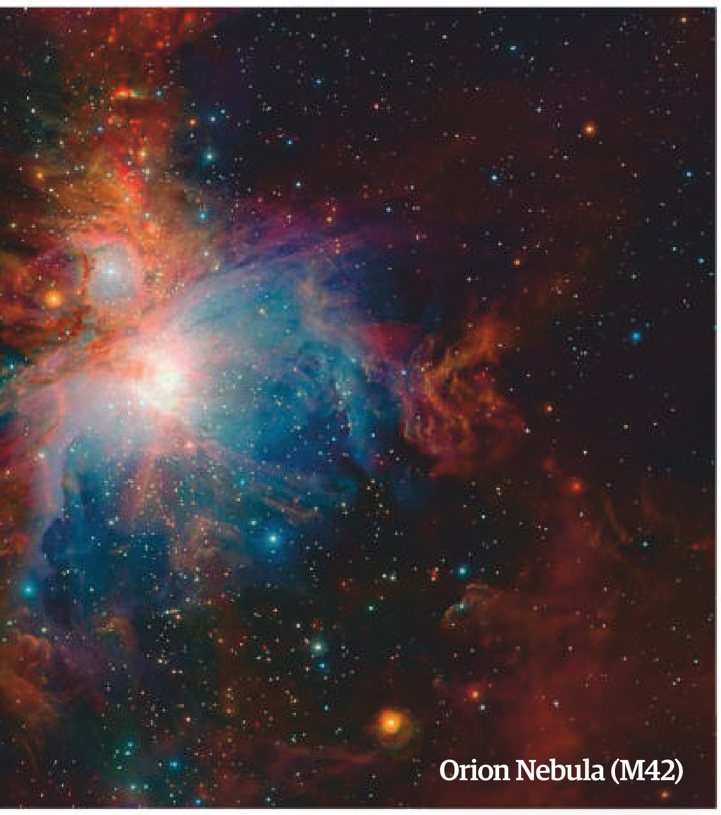
- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



Observer's note:
The night sky as it appears on 17 November 2019 at approximately 22:00 (GMT)

The Northern Hemisphere





Orion Nebula (M42)

© ESO

Messier 77

© NASA, ESA

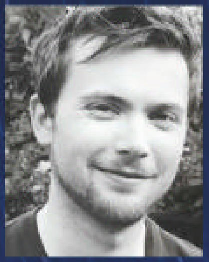
The IRAS 05437+2502 nebula in Taurus

© ESA/Hubble and NASA

Astroshots *of the month*

Send your astrophotography images to **space@spaceanswers.com** for a chance to see them featured in **All About Space**

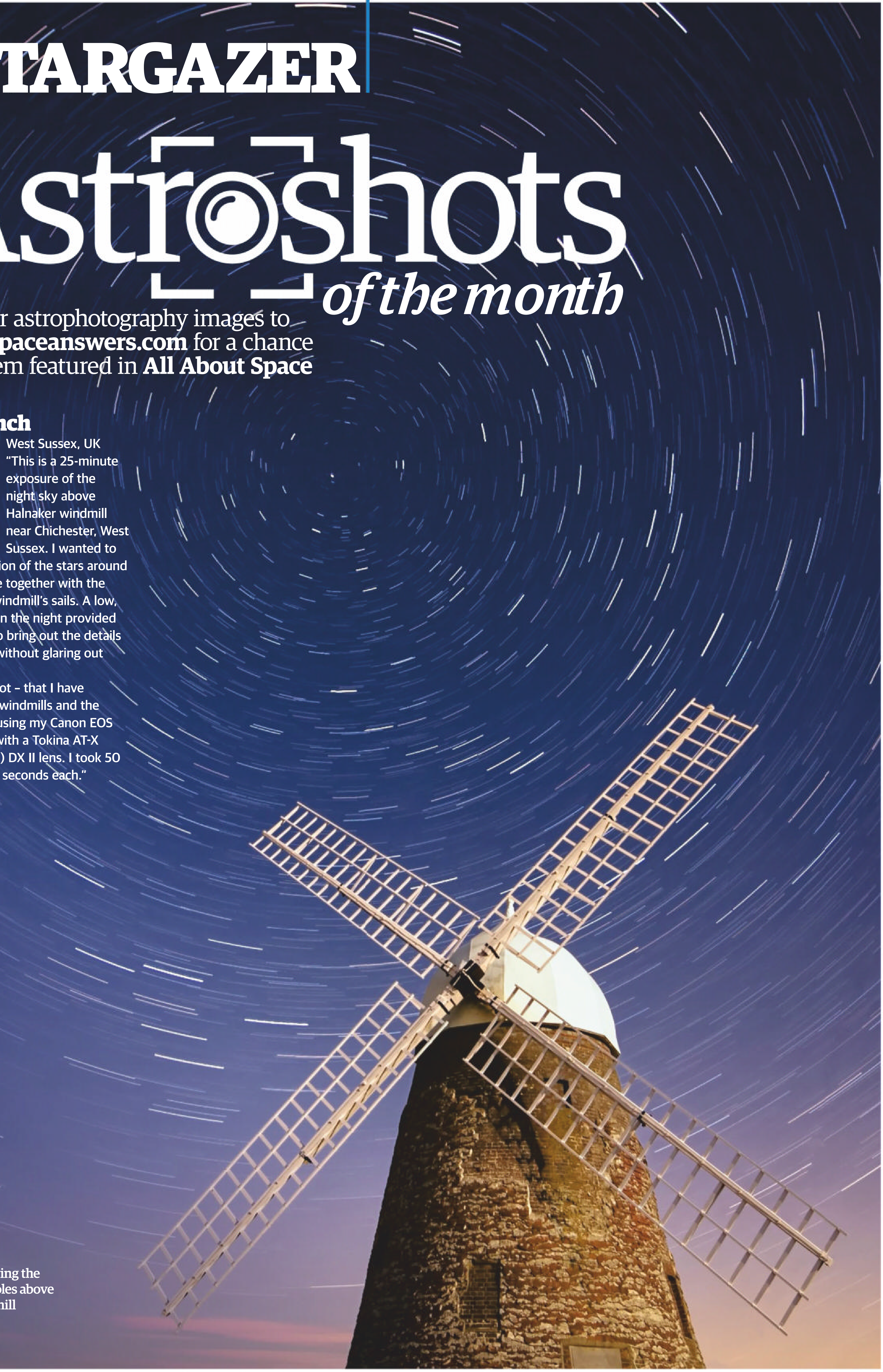
Derek Finch



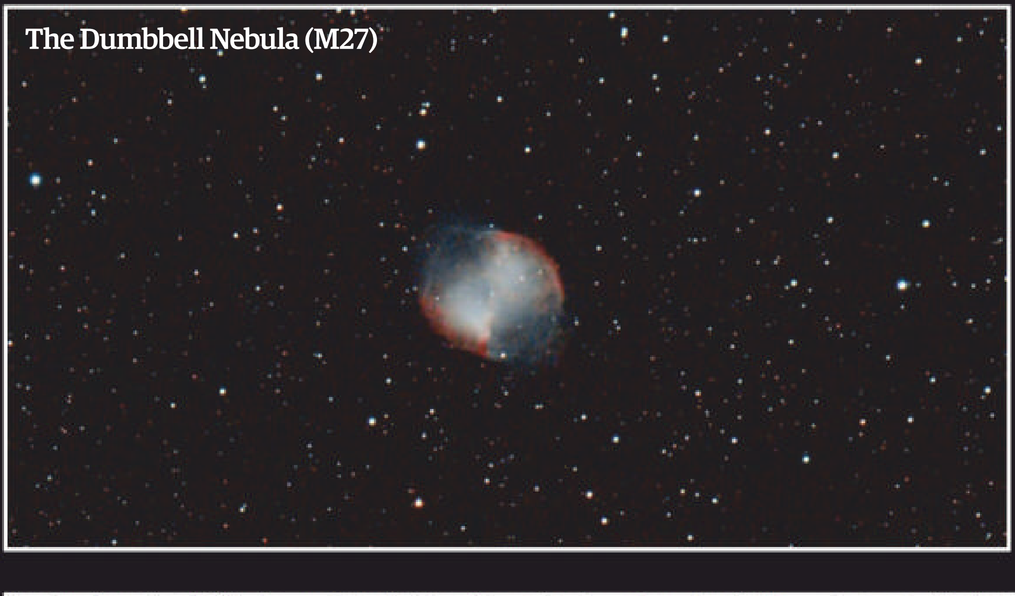
West Sussex, UK

"This is a 25-minute exposure of the night sky above Halnaker windmill near Chichester, West Sussex. I wanted to capture the motion of the stars around the celestial pole together with the stillness of the windmill's sails. A low, near-full Moon on the night provided sufficient light to bring out the details of the windmill without glaring out the sky.

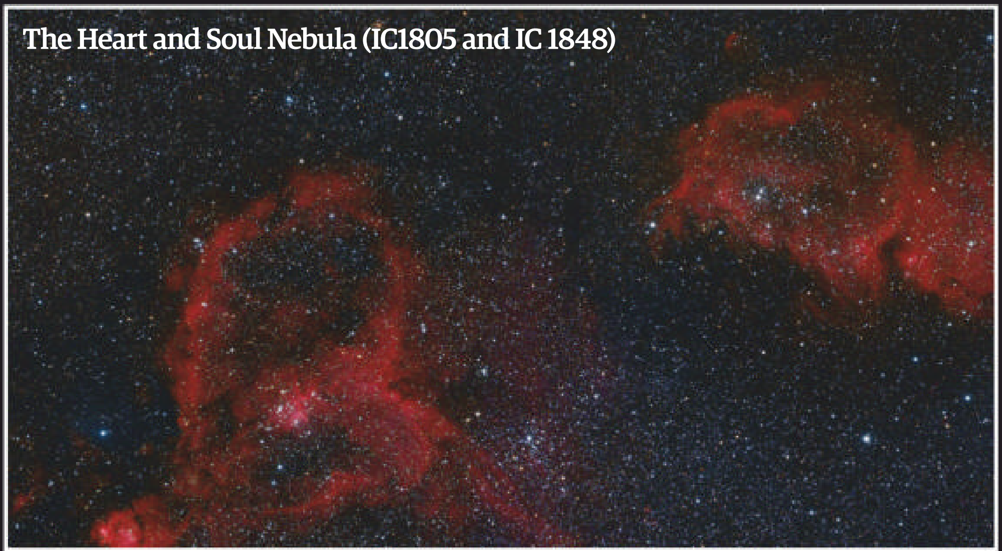
"I took this shot – that I have entitled, 'As the windmills and the heavens turn' – using my Canon EOS 30D combined with a Tokina AT-X PRO 12-24 F4 (IF) DX II lens. I took 50 exposures of 30 seconds each."



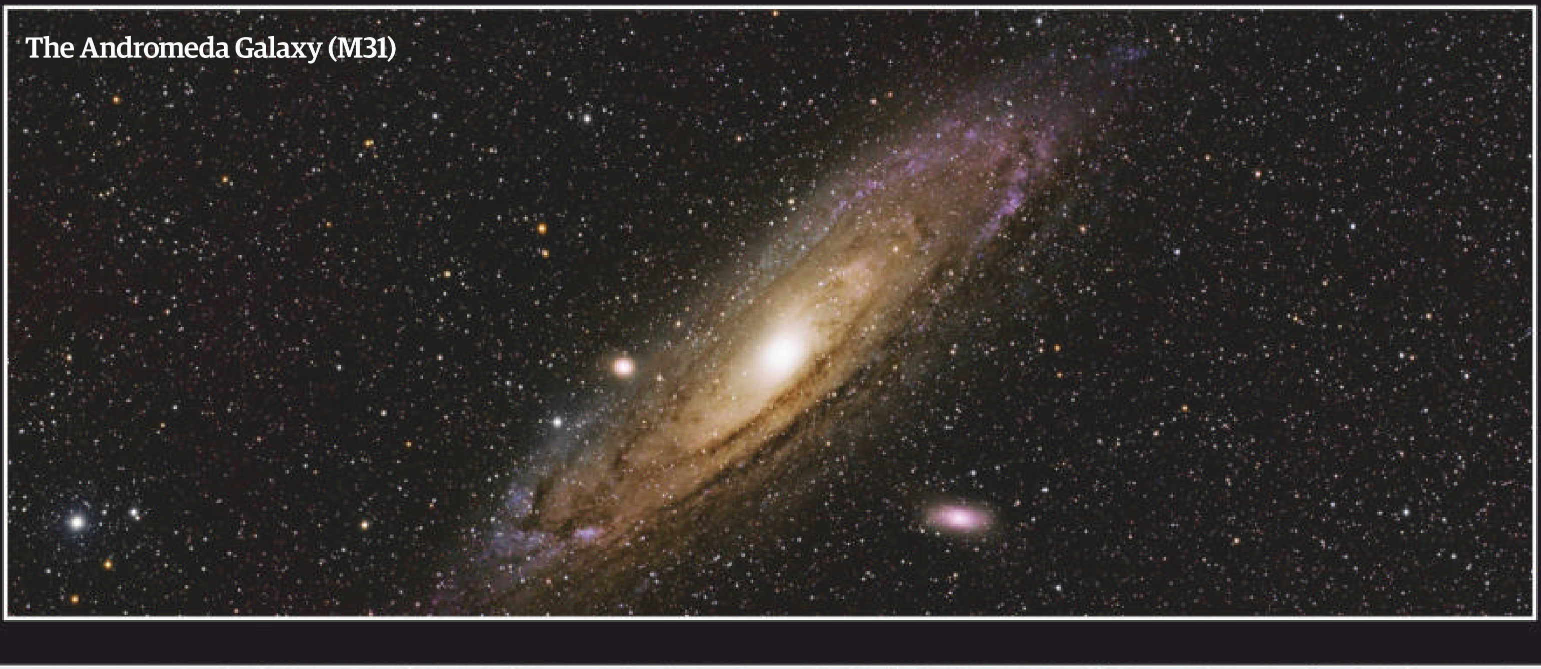
Star trails following the motion of the poles above Halnaker windmill



The Dumbbell Nebula (M27)

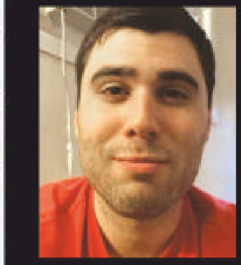


The Heart and Soul Nebula (IC1805 and IC 1848)



The Andromeda Galaxy (M31)

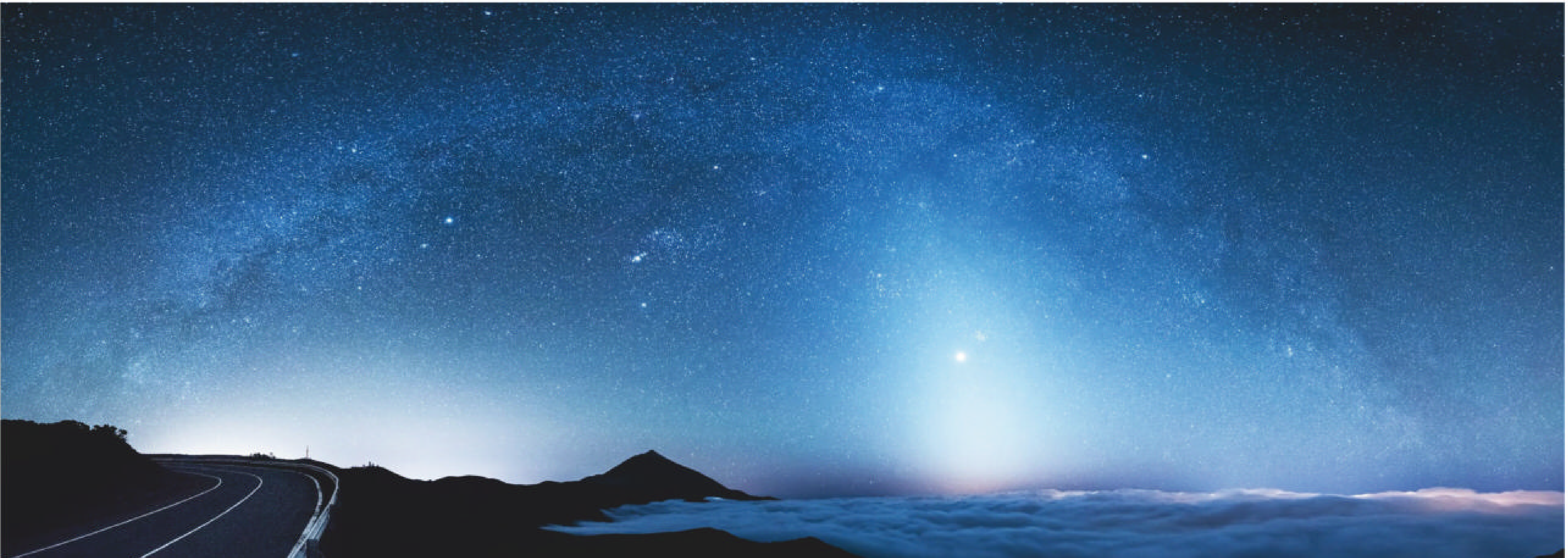
Andrew Genualdi



New Jersey, USA

Telescope: Orion ED80

"I've always loved space, so this was a great hobby to get into. It's pretty challenging at times, but when I get results like these I can't complain. My equipment consists of an Orion ED80, Sirius EQ-G mount, Canon t4i DSLR and PixInsight for post-processing. I've also employed the use of iTelescope.com's T20 mount in Mayhill, New Mexico."



Ollie Taylor

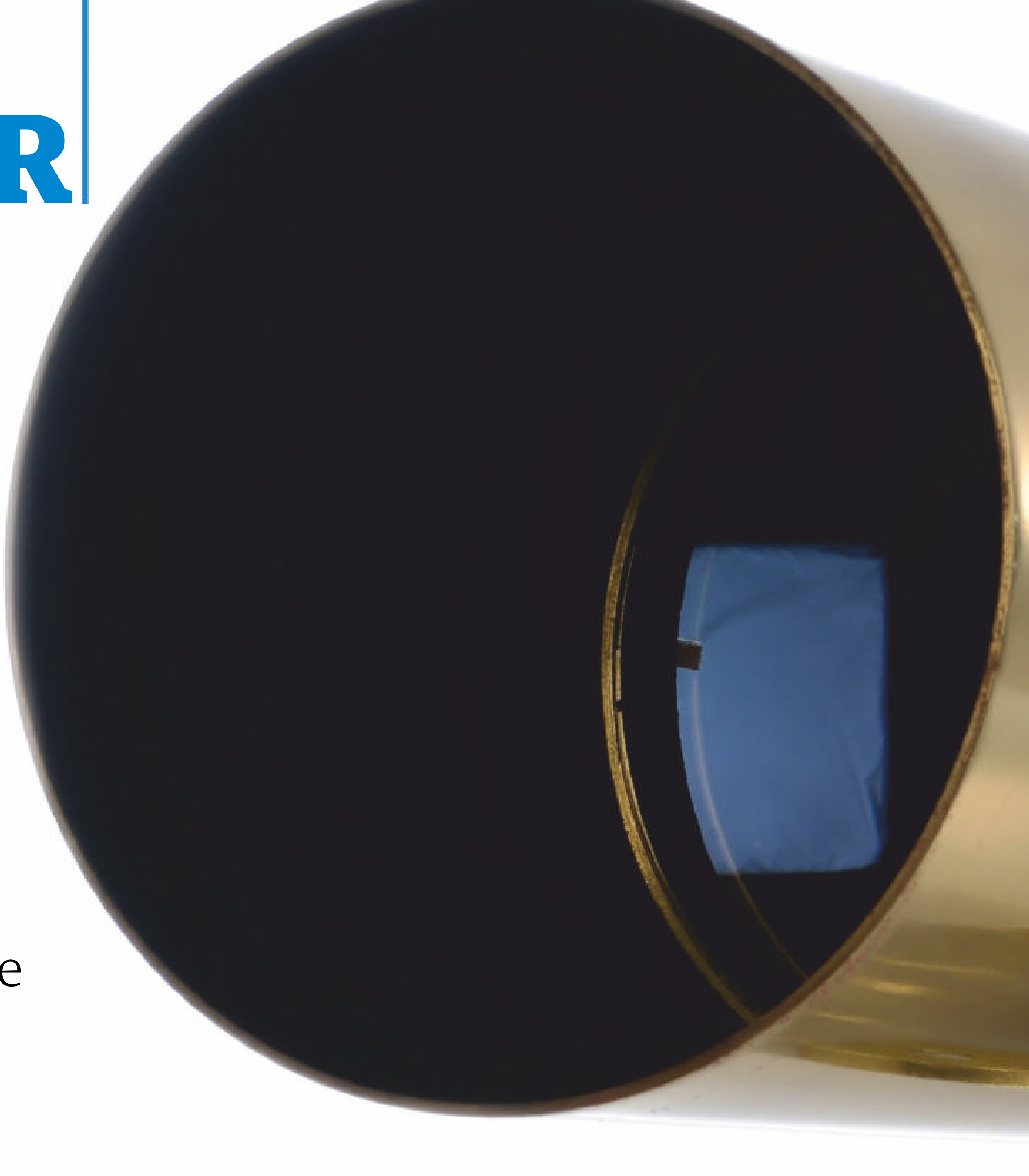
Isle of Portland, Dorset

"I am a landscape photographer based in Dorset. I have been shooting landscapes with an emphasis on the night sky since late winter 2011 after shooting aurorae in Iceland – something I had longed to do for years.

"I have slowly developed my photographic style. In the right places the location opens up to dark skies that appear to stretch out to eternity – just perfect for stargazing. The use of apps to pinpoint the outer band of our galaxy allows me to align it with landscapes to generate nightscapes. One of my recent shots is the Milky Way combined with zodiacal light over Mount Teide in Tenerife."

Zodiacal light and the Milky Way over Mount Teide in Tenerife

Send your photos to... @spaceanswers @ space@spaceanswers.com



Celestron Ambassador 80 AZ

Ideal for observing the lunar surface and bright night-sky targets, this stunning brass refractor is sure to impress casual astronomers

Telescope advice

Cost: £975 / $999.95
From: David Hinds Ltd
Type: Refractor
Aperture: 3.15"
Focal length: 31"

Best for...

- Intermediate
- Medium budget
- Planetary viewing
- Lunar viewing
- Bright deep-sky

Without a doubt the Celestron Ambassador 80 AZ is one of the most beautifully crafted telescopes we have had the chance to review in **All About Space** – almost entirely made of brass, polished to a high finish and affixed to a mahogany tripod. Due to the stunning appearance of the telescope, which also features a brass star diagonal, eyepiece barrel as well as brass-finished lens caps, it seems a shame to pack it away after use – if you have the room, the Celestron Ambassador 80 AZ doubles up as an ornament for your home and will certainly be a conversation starter. While its appearance does look old-fashioned, this refractor is versatile in that it accepts the standard 1.25-inch astronomical eyepieces, and given our daytime views we found that the optics are of good standard, providing decent clarity and contrast.

Setting the Ambassador 80 AZ up was nothing short of a breeze. However, we did take extra care in putting the refractor together, given its more 'unusual' materials. The tripod is sturdy thanks to an accessory tray affixed securely to the legs using washers, wing nuts and machine screws. However, once we had set everything up and began moving the telescope out for a night of observations, it became quite awkward to carry, forcing us to remove the accessory tray and only attach it to the tripod once we had reached an observing spot. This made the set-up that little more time-consuming – due to fiddly washers – and we had to take special care in setting it up under very minimal light.

Slewing the telescope across various sections of the sky, we noted that its mount operated smoothly in its altitude movement, but at first we found that the azimuth direction was a tad stiff until we loosened the nut on the underside of the mount head. We also found that the mount on this telescope makes it difficult to observe any higher than halfway up in the sky – about 45 degrees to the zenith – so we were limited to what we could observe with this telescope and with the included 25mm eyepiece. Many may be used to using a Crayford focuser to bring views through a telescope into focus, however, the Ambassador 80 AZ sharpens views of targets using a rack-and-pinion focuser that works well, but may take some getting used to if you are unfamiliar with using one.

Given its location in the sky, a first quarter Moon with its 53 per cent illuminated surface was an ideal target to observe with the Ambassador 80 AZ. Views of the lunar seas such as Mare Crisium (Sea of Crises), Mare Fecunditatis (Sea of Fertility) and Mare Tranquillitatis (Sea of Tranquillity) looked beautiful through the refractor, with very good resolution and high contrast, as did the craters that stood out along the terminator. The craters Aristoteles, Janssen, Piccolomini and Theophilus in particular caught the Sun's light very well and were a pleasure to observe through the optics of the Ambassador 80 AZ. During our observations we noted the sturdiness of the mahogany wood

Left: The Ambassador 80 AZ is supplied with a beautifully coated 25mm eyepiece, which is optically sound

> "During our observations we noted the sturdiness of the mahogany wood tripod"

tripod, which seemed to resist any shaking as we brought lunar surface features into view using the focuser. Sadly, as with many refractors, we experienced a degree of colour-fringing – also known as chromatic aberration.

The Celestron Ambassador 80 AZ is ideal for casual observing, as well as serving as a beautiful ornamental piece for the home. While the optics of this refractor are very good compared to other brass telescopes that we have used, we wouldn't recommend this telescope for those just starting out in astronomy since it doesn't have the light-gathering capacity of many instruments on the market. The 1.25-inch eyepiece holder offers versatility in terms of increasing the magnification of the telescope, but we found that we had to be careful in how high we pushed the instrument to its limit – too high and we received blurry views of the lunar surface.

The telescope promises to last for many observing sessions to come, but only if lightly used. Since it is mainly comprised of brass, low temperatures will cause the brass to shrink, so we advise being selective of when and where you use it – it would be best to have a much 'sturdier' telescope to hand if you're looking to observe the night sky for hours on end and are looking to observe a variety of objects in the Solar System and deep-sky categories.

Upright: With its polished brass appearance, the Ambassador 80 AZ makes for a stunning ornamental piece

Below: The optical capacity of this refractor is good for casual observing of the night sky

WIN
MEADE ETX-125 OBSERVER

An astronomer needs the right tools, and this telescope is the perfect partner

Do you want to marvel at the night sky but need the companionship of a computer to help show you around? Look no further. One of Meade's masterpieces is waiting to be won. The ETX-125 Observer telescope flaunts a Maksutov-Cassegrain design, allowing for observations at a higher magnification to bring fantastic views of a vast range of objects, such as the planets, double stars, globular clusters and so much more.

The 127-millimetre (five-inch) aperture and 1,900-millimetre (75-inch) focal length provide a focal ratio of f/15, which is perfect for high-power astrophotography. Along with its full-sized steel tripod, an EQ tilt plate and a database of over 30,000 celestial objects, there would never be a dull moment for an astronomer. This telescope is perfect for an amateur astronomer that wants to move out of the realm of beginner and into the intermediate, dabbling in the art of astrophotography in the process.

To be in with the chance of winning, all you have to do is answer this question:

Who was the commander of the Apollo 12 mission that launched on 14 November 1969?

A: James Lovell

B: Neil Armstrong

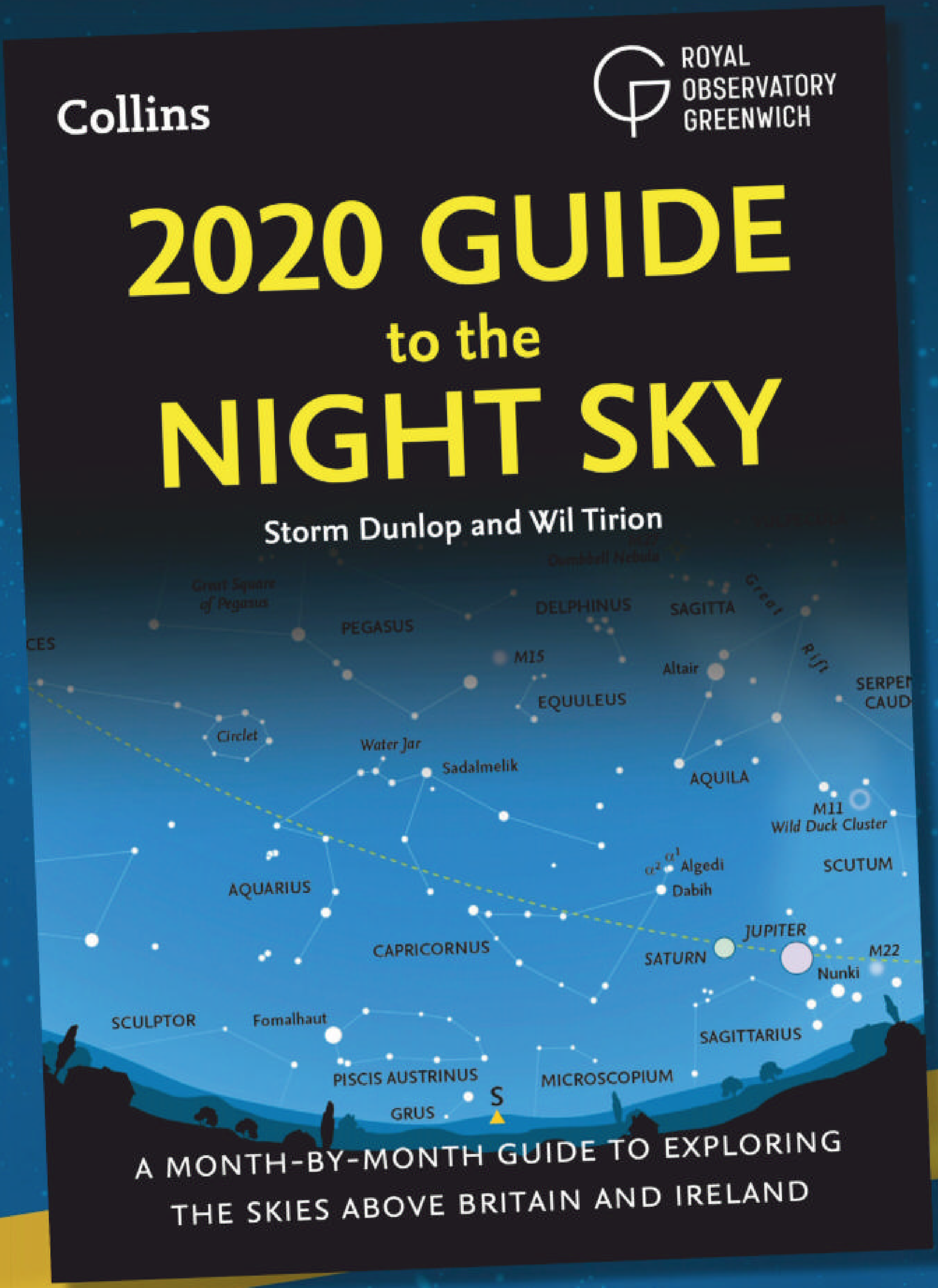
C: Charles "Pete" Conrad

Competition ends on 5 December 2019

Enter online at **Spaceanswers.com** or by post to **All About Space competitions, Richmond House, 33 Richmond Hill, Bournemouth, BH2 6EZ**

Visit the website for full terms and conditions at **spaceanswers.com/competitions**

BESTSELLING MONTH-BY-MONTH GUIDE TO THE NIGHT SKY



Collins

ROYAL OBSERVATORY GREENWICH

2020 GUIDE to the NIGHT SKY

Storm Dunlop and Wil Tirion

A MONTH-BY-MONTH GUIDE TO EXPLORING THE SKIES ABOVE BRITAIN AND IRELAND

For all astronomy enthusiasts, from beginner to seasoned stargazer

Includes:

- Advice on where to start looking
- Easy-to-use star maps for each month with descriptions of what to see
- **NEW** Special, detailed charts for positions of planets, minor planets and comets in 2020
- **NEW** Seasonal charts
- **NEW** Details of dark sky sites
- Details of objects and events you might see in 2020

THE PERFECT GIFT THIS Christmas

Collins

In association with ROYAL MUSEUMS GREENWICH

Christmas gift guide

With the holiday season just around the corner, **All About Space** selects the space gifts sure to delight any fan of the universe

Best for observers

Meade Infinity 76

Cost: £129.99 (~€149.99/$165.00) **From:** currys.co.uk

Introduce your loved ones to the wonders of the night sky with the Meade Infinity 76 – the straight-from-the-box, no-nonsense telescope designed to get astronomers of every age and ability stargazing in minutes. Budding astrophotographer? Perfect! Exclusively included with the Infinity 76 is Meade's universal smartphone mount to snap and share all those stunning celestial views! Smooth tracking controls and a nifty red-dot finderscope help provide a limitless supply of stars, planets and other space objects to locate and discover, conveniently packing away within the signature Meade blue travel bag for astronomy on the go.

Best for unaided astronomers

Night Sky: Stargazing with the Naked Eye

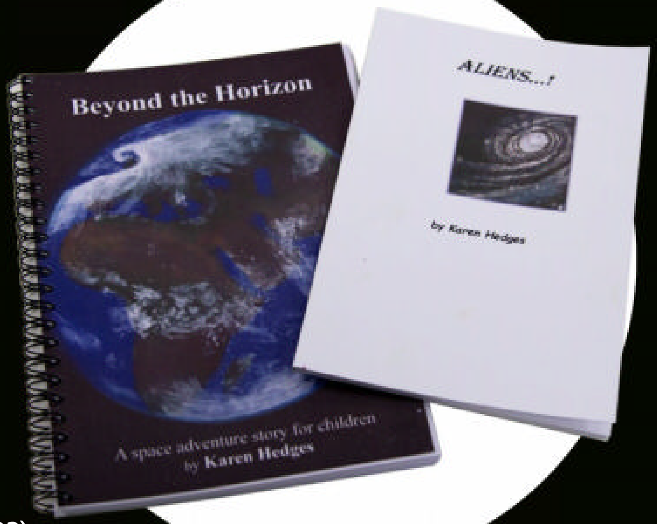
Cost: £19.99 (~€22.81/$29.95) **From:** Amber Books Ltd

Can you spot the Big Dipper in the night sky? Or Orion's Belt? Or Cassiopeia? Even in cities or without the aid of a telescope, these are a few of the easier constellations to find. In fact, a great deal can be seen in the night sky with the naked eye – if you know what you're looking for. *Night Sky* presents 200 colour photographs of stunning nocturnal vistas all visible to the naked eye. From the majesty of the northern lights (aurora borealis) as seen from Norway or Canada and the southern lights (aurora australis) as seen from Australia to seeing the clarity of the Milky Way over an Italian forest, from witnessing a lunar eclipse in Indonesia to charting the course of the International Space Station across the Indian night, from seeing a Geminid meteor shower in New Mexico to recognising the Great Bear (Ursa Major) constellation over New England, the book is a feast of nocturnal delights. Where necessary, additional inset photographs indicate the formation of a constellation.

Best for seasoned stargazers
Stars and Constellations Glow Map

Cost: £20 (~€22.82/$25.40) **From:** mapsinternational.co.uk
The Stars and Constellations map is a stunning gift for seasoned stargazers this Christmas. Packed with fascinating information on the cosmos, it includes detailed constellations and illustrations of planets in our Solar System, plus satellites, lunar positions, eclipses, meteors and comets. It even charts the life cycle of a star from giant to dwarf sizes, and supernovae to black holes.

Printed with glow-in-the-dark ink that charges with light during the day, it glows for approximately 12 hours at night so you never need to worry about seeing the night sky on a cloudy or light-polluted night! **All About Space** readers can get 20 per cent off with the code AASPACEMAP10.



Best for children
Stellar story books

Cost: Beyond £4.99 (~€5.70/$6.33)
Aliens £5.99 (~€6.84/$7.60)
From: karenhedges.co.uk
Aliens is a story about a rather special planet and is another in the series of space adventures of Lucy, Danny and Peter. Their adventures begin in *Beyond the Horizon,* in which the heroes set off on their first space mission to the Moon and then visit the other planets in our Solar System. They are guaranteed an exciting adventure!

Karen Hedges is an enthusiastic amateur astronomer and former teaching assistant. She is a member of the Norman Lockyer Observatory Society in Devon.

Best timekeeper
Royal Observatory Greenwich Shepherd 24-hour Wall Clock

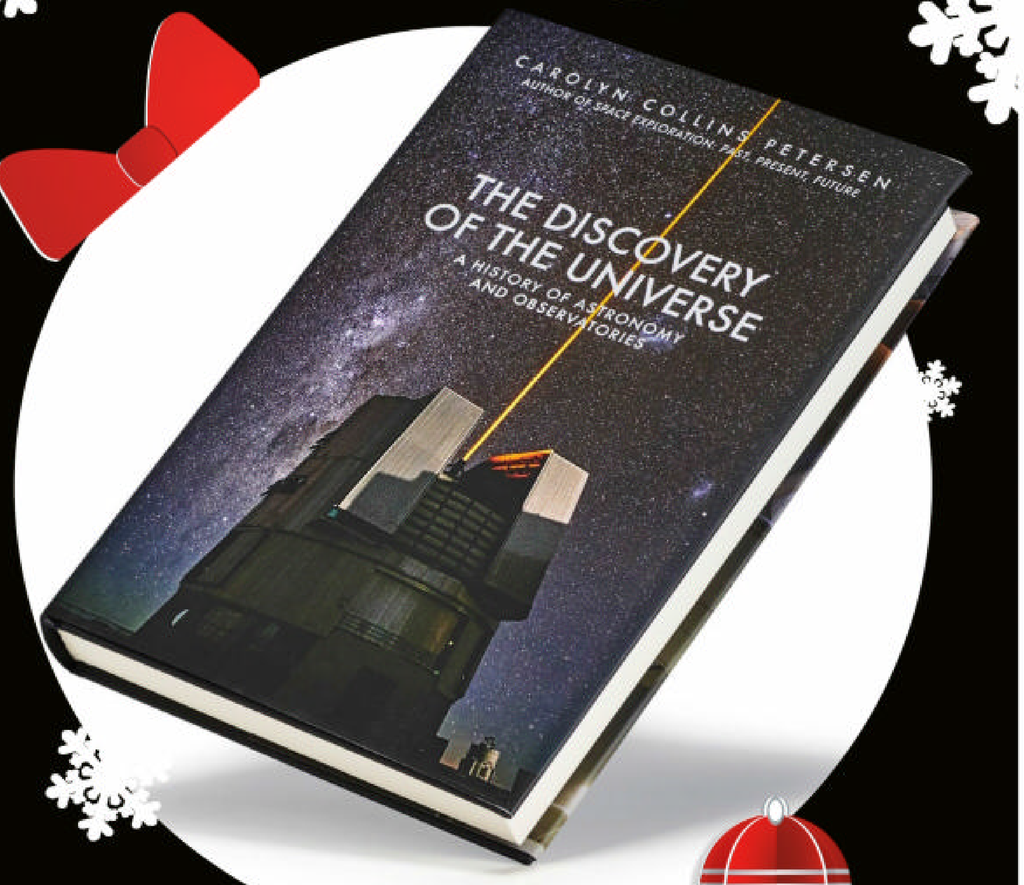
Cost: £150 (~€171.19/$190.37) **From:** shop.rmg.co.uk
Own an exclusive, beautiful, small-scale replica of the world-famous Shepherd Clock from the Royal Observatory Greenwich. The minute and second hands are conventional, but the hour hand goes round the dial once in 24 hours. Thus at midday the minute hand points to the top, but the hour hand points to the bottom.

The clock has two movements – one is for the main clock movement, the other counts the seconds. With a casing that's made of metal and a window comprised of glass, this stunning timepiece will add class to any room in which it is adorned. Suitable for indoor use only.

All About Space EDITOR'S CHOICE

Best for armchair astronomers
The Discovery of the Universe

Cost: £20 (~€22.82/$25.40) **From:** Amberley Books
The Discovery of the Universe charts the progress of astronomy through the observatories used throughout history, from the earliest such as Stonehenge to places like Birr Castle with its Leviathan telescope used by Herschel, places where the secrets of the universe were first unlocked by science. These technological marvels range from the Mauna Kea Observatories in Hawaii to the South Pole Telescope in Antarctica that hunts for the faint emissions of the cosmic microwave background. Astronomers can now routinely look across the cosmos at objects that existed at nearly the beginning of time. They have studied distant Earth-type planets, delved into stellar birthplaces, examined the minutiae of stellar explosions and galaxy collisions and searched out the signatures of chemical elements that form the basis of the planets and ourselves. The *Discovery of the Universe* looks at the amazing science that has been done using the world's suite of observatories.


CAROLYN COLLINS PETERSEN
AUTHOR OF SPACE EXPLORATION: PAST, PRESENT, FUTURE
THE DISCOVERY OF THE UNIVERSE
A HISTORY OF ASTRONOMY AND OBSERVATORIES

Giovanni Battista Riccioli

An underrated astronomer of the 17th century, who was responsible for naming lunar features

Some popular, well-known names in astronomy are Johannes Kepler and Nicolaus Copernicus, known because of their groundbreaking discoveries. However, a name often overlooked from the same era is Giovanni Battista Riccioli, who contributed hugely to astronomy and theology.

Born on 17 April 1598 in Ferrara, Italy, Riccioli moulded himself into a revolutionary thinker, studying - and later teaching - philosophy and theology in Parma and Bologna, both in Italy. He became a Catholic priest in the Society of Jesus, also known as the Jesuit order, but his work in astronomy during such an influential time has been severely underappreciated. The pinnacle of his work came in 1651 with an encyclopaedia of over 1,500 pages, which has been dubbed by Edward Grant, a historian of science, as "the lengthiest, most penetrating and authoritative analysis made by an author of the 16th and 17th centuries". The title of this encyclopaedia is the Almagestum Novum, or the New Almagest.

The New Almagest covered all areas of astronomy in this period, and most famously put the Copernican theory under the microscope. In his work Riccioli outlined 126 arguments both for and against the theory of the heliocentric model. His work presented 77 arguments against it and 49 for, leaving the majority vote in favour of the Earth being at the centre of the universe. However, he did not endorse the geocentric model. Instead he believed it was somewhere between the two in a 'geo-heliocentric' model, much like that hypothesised by Danish astronomer Tycho Brahe around the same time. This model would have had the Sun, the Moon and the stars orbiting the centre of the universe, Earth, while the other planets still orbited the Sun.

Now we know this is not the case, but the arguments that Riccioli laid out were based on hypotheses that could not be explained scientifically at the time, though he still analysed the arguments diligently and rationally. Riccioli also contributed greatly to our knowledge of physics and astronomy in the New Almagest, which included work regarding pendulums and free-falling objects, aiding the measurement of acceleration due to gravity and, most notably, the naming of features on the Moon.

Riccioli, with the help of his friend Giuseppe Biancani, extensively mapped the Moon and named the lunar features - names which are still used today. A famous example of how this application of lunar nomenclature has affected us in modern times is the Apollo 11 mission landing in the Sea of Tranquillity (Mare Tranquillitatis), which was given its name by Riccioli himself. Despite his bias towards the Copernican theory, Riccioli still named craters after Copernicus and his pro-heliocentric astronomers.

Riccioli worked in astronomy until his death, which came on 25 June 1671 in Bologna, Italy. Sadly he is not quite the household name that Copernicus and Kepler are, but his contributions documented in the New Almagest are no less important, helping to shape the world of astronomy we all know and love today.

RICCIOLI DELLA COMPA. DI GIESU
GIOVAN BATTISTA

Riccioli argued against Copernicus' heliocentric model, but also made points supporting it

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> "Riccioli, with the help of his friend Giuseppe Biancani, extensively mapped the Moon and named the lunar features"

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Future PLC Richmond House, 33 Richmond Hill, Bournemouth, Dorset, BH2 6EZ

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Editor-in-Chief **Gemma Lavender**
gemma.lavender@futurenet.com
Art Editor **Jonathan Wells**
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Photography **Olly Curtis**

Contributors
Stuart Atkinson, Meghan Bartels, Charles Q. Choi, David Crookes, Adam Markiewicz, James Romero, Giles Sparrow, Michael Wall

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Media packs are available on request
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Regional Advertising Director **Mark Wright**
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Account Director **Andy Baker**
andy.baker@futurenet.com
01225 687 520
Account Manager **Jagdeep Maan**
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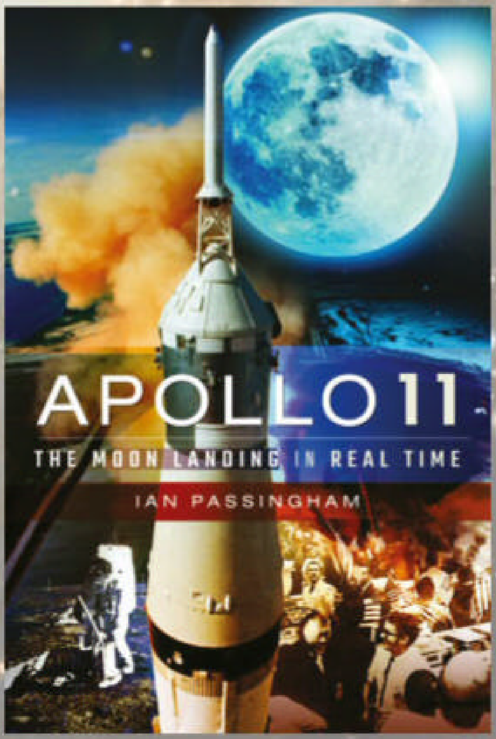

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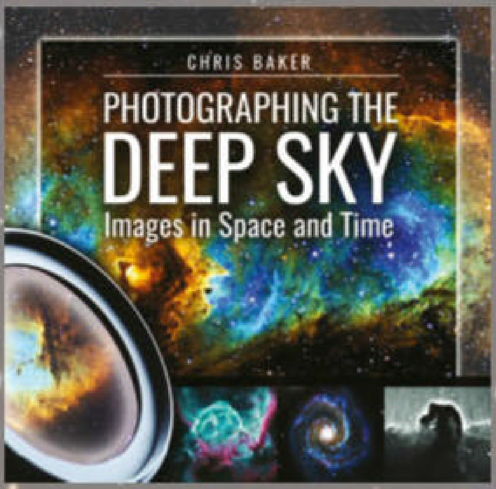

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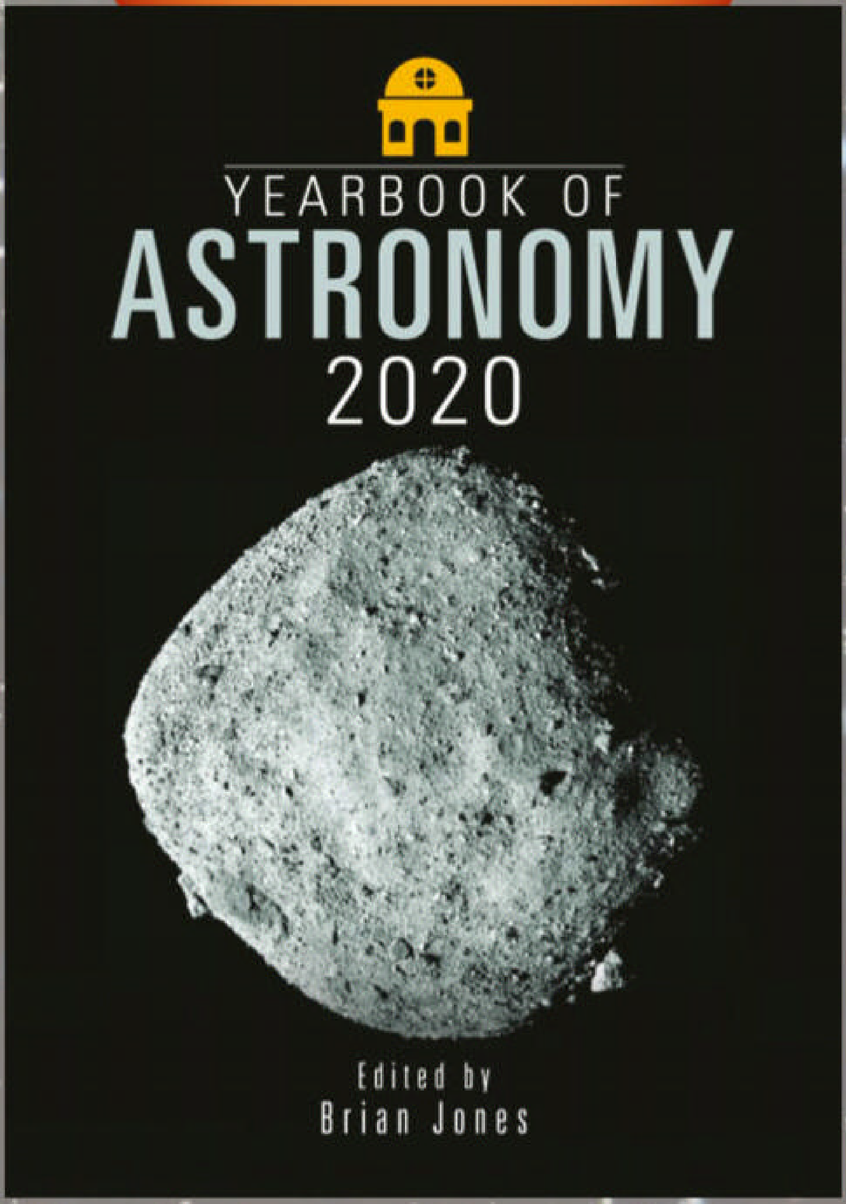

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